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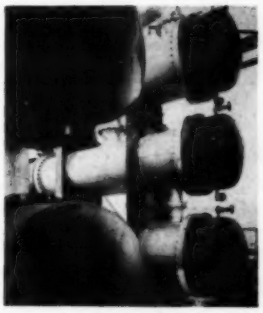

A group of overhead condensers on the vacuum and atmospheric columns of the crude distillation unit at the Mobil Co.'s refinery at Coryton.

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B.C.E., 4, No. 3, 130. U.D.C. No. 66.045.2-97.

DIAGRAMMES DE TRANSMISSION DE CHALEUR POUR DES CONDITIONS LIMITES VARIANT AVEC LE TEMPS

par Taghi J. Mirsepassi

Des diagrammes sont présentés pour la détermination: (1) de la température dans un solide demi-infini quand la température limite est une fonction du temps établie arbitrairement, (2) une température limite inconnue à partir d'une observation de température donnée d'un point dans le solide. Alternativement, les écoulements de chaleur dans ces deux cas peuvent être déterminés.

B.C.E., 4, No. 3, 138. U.D.C. No. 66.045.1:661.66.

CONSIDÉRATIONS SUR LA CONSTRUCTION DES ÉCHANGEURS DE CHALEUR GRAPHITIQUES

par A. Hilliard

L'auteur décrit une construction d'un échangeur de chaleur graphitique basée sur les propriétés du matériel de construction sans tenir compte de la pratique antérieure. Le système de construction par unités possède les avantages de la robustesse, de la résistance à la corrosion et de l'étanchéité, ainsi que des taux de transmission de chaleur très élevés accompagnés par des pertes de charge reduites.

B.C.E., 4, No. 3, 144. U.D.C. No. 66.045.1-712.

CONSIDÉRATIONS ÉCONOMIQUES SUR LES ÉCHANGEURS DE CHALEUR À REFROIDISSEMENT D'AIR

par G. Winters

L'intérêt dans le matériel à refroidissement d'air se fait plus élevé étant donné la pénurie d'eau de refroidissement. L'influence de plusieurs facteurs tels que la période d'amortisation, le coût de l'échangeur et du ventilateur, la consomption d'énergie, l'approvisionnement d'eau disponsible et les conditions d'installation différentes est discutée.

B.C.E., 4, No. 3, 148. U.D.C. No. 66.045.5:536.2.

LA CONSTRUCTION DES CONDENSATEURS RÉFRIGÉRANTS

par J. Madejski

Une méthode ameliorée pour la détermination des dimensions d'un condensateur réfrigérant est décrite. Cette méthode, par contraste aux méthodes antérieures, tient compte de la perte de charge sur le côté condensateur de l'échangeur. L'application des formules dérivées par l'auteur est illustrée par un exemple étudié de la construction d'un condensateur réfrigérant pour un mélange chlore-hydrogène.

B.C.E., 4, No. 3, 160. U.D.C. No. 66.045.2: 66.045.5.

TRANSMISSION SIMULTANÉE DE CHALEUR ET DES MASSES DANS LES RÉFRIGÉRANTS À CHEMINÉE

par W. J. Thomas et P. Houston

L'influence des taux d'air et d'eau sur l'éfficacité des réfrigérants à cheminée est étudiée. Les auteurs indiquent comment les valeurs des coefficients individuels de transmission des masses et de chaleur pour la phase gazeuse et le coefficient de transmission de chaleur du filme liquide sont influencées par les taux de l'eau et de la liqueur. Les taux de la liqueur utilisés dans les marches d'éssai comprennent le taux moyen effectif du liquide du remplissage.

Kurzreferate

B.C.E., 4, No. 3, 130. U.D.C. No. 66.045.2-97.

WÄRMEÜBERGABEDIAGRAMME FÜR ZEITVERÄNDERLICHE GRENZBEDINGUNGEN

von Taghi J. Mirsepassi

Diagramme für die Bestimmung von (1) der Temperatur in einem quasiunendlichen Festkörper, wenn die Grenztemperatur eine willkurlich aufgestellte Funktion der Zeit ist, (2) einer unbekannten Grenztemperatur durch eine gegebene Temperaturbeobachtung eines Punktes in dem Festkörper, werden vorgeschlagen. Wahlweise können die Wärmeströme in diesen beiden Fällen bestimmt werden.

B.C.E., 4, No. 3, 138. U.D.C. No. 66.045.1:661.66.

BETRACHTUNGEN ÜBER DIE PLANUNG VON GRAFITWÄRMEAUSTAUSCHERN

von A. Hilliard

Der Autor beschreibt eine Ausführung eines Grafitwärmeaustauschers aufgrund der Eigenschaften des Konstruktionsmaterials ohne Bezug auf vorhergehende Praxis. Das System des Aufbaus aus geschlossenen Einheiten besitzt die Vorzüge der Unempfindlichkeit, des Korrosionswiderstandes und der Dichtigkeit zusammen mit sehr hohen Wärmeübergabegeschwindigkeiten und niedrigen Druckverlusten.

B.C.E., 4, No. 3, 144. U.D.C. No. 66.045.1-712.

WIRTSCHAFTLICHE BETRACHTUNGEN ÜBER LUFTGEKÜHLTE WÄRMEAUSTAUSCHER

von G. Winters

Als Folge der Knappheit an Kühlwasser ist das Interesse fur luftgekühlte Einrichtungen im Ansteigen. Der Einfluss einer Anzahl von Faktoren, sowie Amortisierungsperiode, Anschaffungskosten von Austauscher und Gebläse, Energieaufwand, verfügbare Wasserversorgung und verschiedene Einbaubedingen werden besprochen.

B.C.E., 4, No. 3, 148. U.D.C. No. 66.045.5:536.2.

DIE PLANUNG VON KÜHLERKONDENSATOREN

von J. Madejski

Eine verbesserte Methode zur Bestimmung der Ausmasse von Kühlerkondensatoren wird beschrieben, die im Gegensatz zu früheren Methoden das Druckgefälle an der kondensierenden Seite des Austauschers in Betracht zieht. Die Anwendung der vom Autor abgeleiteten Formeln wird mittels eines ausgeführten Beispiels der Planung eines Kühlerkondensators für eine Chlor-Wasserstoffmischung erläutert.

B.C.E., 4, No. 3, 160. U.D.C. No. 66.045.2: 66.045.5.

GLEICHZEITIGE WÄRME— UND MASSENÜBERGABE IN KÜHLTURMEN

von W. J. Thomas und P. Houston

Der Einfluss von Luft- und Wassergeschwindigkeiten auf die Leistung von Kühlturmen wird untersucht. Die Autoren zeigen, wie die Werte der einzelnen Kennziffern der Massen- und Wärmeübergabe für die Gasphase und die Kennziffern der Wärmeübergabe der flüssigen Phase von den Wasser- und Flüssigkeitsgeschwindigkeiten beeinflusst werden. Die in den Versuchsgängen angewandten Flüssigkeitsgeschwindigkeiten schliessen die mittlere effektive Flüssigkeitsgeschwindigkeit der Füllung ein.

Резюме

B.C.E., 4, No. 3, 130. U.D.C. No. 66.045.2-97.

Схемы теплопередачи для временно-переменных граничных условий

Таги Дж. Мирсепасси.

Предлагаются схемы для определения 1) температуры в полу-бесконечном твердом теле, где граничная температура является произвольно построенной функцией времени, 2) неизвестной граничной температуры на основе заданного температурного наблюдения пункта в массе. Альтернативно возможно определить тепловой поток в обоих вышеуказанных случаях.

B.C.E., 4, No. 3, 138. U.D.C. No. 66.045.1:661.66.

Соображения по вопросу конструкции графитных теплообменников

А. Хиллиард.

Автором описывается конструкция графитного теплообменника на основе свойств конструкционного материала без учета предыдущей практики. Система узловой конструкции имеет преимущества прочности, коррозоустойчивости и плотности, а также весьма высоких скоростей теплопередачи с небольшими потерями давления.

B.C.E., 4, No. 3, 144. U.D.C. No. 66.045.1-712.

Экономические соображения на тему теплообменников с воздушным охлаждением

Дж. Уинтерс

В результате недостатка воды для охлаждения, интерес к установкам с воздушным охлаждением все возрастает. Обсуждается влияние ряда факторов, так напр. периода амортизации, себестоимости обменника и дутья, расхода энергии, доступного водоснабжения и различных условий монтажа.

B.C.E., 4, No. 3, 148. U.D.C. No. 66.045.5:536.2.

Конструкция конденсаторов-охладителей

Дж. Мадейски.

Описывается усовершенствованный метод определения размеров конденсатора-охладителя, который, противоположно известным методам, учитывает перепад давления на конденсирующей стороне охладителя. Применение приведенных автором уравнений иллюстрируется путем проработанного примера конструкции конденсатора-охладителя для хлоро-водородной смеси.

B.C.E., 4, No. 3, 160. U.D.C. No. 66.045.2: 66.045.5.

Одновременная массовая и теплопередача в градирнях

У .Дж. Томас. и П. Хустон

Изучается влияние скоростей воздуха и воды на работоспособность градирень. Авторы из'ясняют влияние скоростей воды и жидкости на значения отдельных коэффициентов массовой и теплопередачи для газовой фазы и коэффициента теплопередачи для жидкой пленки. Скорости жидкости, применяемые при опытном ходе, включают среднюю эффективную скорость жидкости в насадке.

DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

Through the Linguistic Curtain

VAST expansion of the chemical industry in the U.S.S.R. (see *British Chemical Engineering* 1958, 3, No. 7, p. 394) gives added point to the efforts being made by D.S.I.R. to supply British scientists and engineers with up-to-date information on Russian developments. A new publication "LLU Translations Bulletin" contains lists of books, journals and other scientific papers which are now available or which are being translated and will become available in the near future. One section deals with cover-to-cover translations—a scheme for providing a complete Russian technical journal in the English language—and another gives details of the work being carried out by the National Science Foundation in the United States, with whom the L.L.U. collaborates in this translation scheme. Many translations from America are held in London on microfilm and photo-copies may be borrowed. Among the first 24 journals due to be regularly fully translated are Khimicheskaya Nauka i Promyshlennost' (Chemical Science and Industry) and Khimicheskaya Promyshlennost' (Chemical Industry). Complete sets of abstracts of these journals are already being published in America and these are available on loan from the Lending Library Unit of D.S.I.R.

The service is likely to be expanded because we understand that D.S.I.R. are examining the list of new Russian specialist chemical journals which started publication in January in connection with their development programme.

Publication at this moment of a British Standard (B.S. 2979:1958) for the transliteration of Cyrillic and Greek is peculiarly timely. It provides guidance on both the system generally used for representing these characters in English and also those in other countries using the Roman alphabet. The need for this guide can be better appreciated after learning that the Russian name which would be rendered Shchedrin in English would be given as Szczedrin in Polish, Chtchedrine in French and Schtschedrin in German. There are also other variants. Without this guide one might well fail to pick up a useful paper in an internationally compiled catalogue or list through failing to recognise the author's name.

Pleasure-seeking Through Systems Engineering

IT is an attractive idea to control processes by using a computer continuously to calculate the conditions required to give desired quality rather than waiting for properties of a product to deviate from specified values and correcting matters in arrears. In the simplest example quoted by PROFESSOR SELLERS, in an address to the Institution of Chemical Engineers (North-Western Branch), this principle can be applied even for water-heating where temperature control is critical. Essentially, the aim is to control plant so that defective material is never produced. In a phrase, this may be described as feed forward rather than feed back. At present every effort is made to achieve stable operating conditions in massive equipment with buffer devices between units. PROFESSOR SELLERS supported the claim of systems engineers that a new strategy based on dynamic design analysis would result in much more efficient use of equipment. These principles were further illustrated by a simplified example of a plant for a polymerisation process; any possible restrictions were considered in the design and a digital computor was coupled directly to the controls to enable the plant to operate all the time for maximum profit. All of this is connected with a future approach to design of plants and processes which will have a greater mathematical content, although the impact on the engineer is slightly softened by the use of the risqué-sounding phrase "seeking for maximum hedony." Dictionaries—those obsolescent compendia—define hedony solely in terms of a doctrine of pleasure but the systems engineer uses the word to describe a desired objective, which in turn has to be defined by the producer. For many private producers the point will simply be, not the most efficient way of making chemicals, but how to maximise profit. This involves deriving a mathematical function for profit in terms of process variables and maximising it by normal mathematical techniques using partial differentiation with respect to selected variables in turn and solving the resultant equations.

It Moves

WHETHER Lunik, the Advisory Council on Science Policy, or the technical press can take credit, or whether the change is due to a resultant of all three is a matter of opinion; the fact is that the Government has loosened up a little in its provision for civil science. Expenditure on research by the Department of Scientific and Industrial Research will be nearly doubled in the next five years. Expansion will continue steadily throughout the period and for the year 1963-64 expenditure is planned to reach about £14m. (But total government expenditure on research and development in the current year is estimated to cost £265m. plus an undisclosed amount for atomic energy.) Post-graduate awards to students will be increased by about 10% each year and, in the Department's own laboratories, staff will increase at the rate of about 6% per annum. Grants to the Research Associations will also go up to over £2m. per annum by the end of the period, but the Council for Scientific and Industrial Research will continue its policy of encouraging industry to bear an increasing proportion of the total cost. To encourage further application of results more attention and more money will be devoted to ensure that the results of scientific research are made known. There will also be a substantial increase in the number of DSIR Post-graduate Studentships and Fellowships in science and technology. There are now nearly 1900 post-graduate students supported by DSIR and this number is expected to double over the five-year period. DSIR Grants* for Special Researches to assist research

projects in science and technology at universities and colleges go up between three and four fold, reaching £1¼m. for 1963/64.

Part of the former Royal Ordnance Factory at Thorp Arch, near Boston Spa, Yorks, will be taken over for the use of the new National Lending Library for Science and Technology. The library should begin operating at Thorp Arch in 1961 and become fully operational during the following year. Meanwhile the universities are to get an increase of more than £2¼m. a year in Treasury grants for the last three years of the current five-year period ending 1962. The present grant is about £34m. and the increase is needed because the rise in student numbers is faster than planned.

After unfolding this catalogue of bounties, it seems almost ungracious also to refer readers to a PEP† pamphlet on manpower which concedes that the government is moving, but carefully and critically examines whether the movement is fast enough.

* Details in "Notes on DSIR Grants for Graduate Students and Research Workers," HMSO, 1959, 1s. 9d.

† "Scientific and Engineering Manpower Survey" by Richard Fort, M.P., Political and Economic Planning, 1959, 2s. 6d.

Teaching Aid for Refrigeration Fitters

"INTERESTING and useful" was the comment of a leading research worker in the low temperature field when we showed him the products of a running project by technical committees of the German refrigeration industry. This consists of issuing at intervals a set of printed instructional notes* for fitters and their teachers. Four series are proposed—technical calculations, physics, refrigeration and electrical technology—and we have received samples of the first three. Each set goes into a loose-leaf folder, the sheets being serially numbered. Presentation and layout are admirably clear. The authors have succeeded in their aim of building up the instructional material as simply as possible—from a quick reminder of basic arithmetic to the use of the slide rule in calculation, and correspondingly in the other subjects. Special value is attached to examples which are frequent and worked out in detail to help the student in grasping principles. In a preface, Herr Katzenberger, Chairman of two of the sponsoring committees, points out that extensive demands are made on refrigeration mechanics, requiring a fundamental and many-sided schooling.

Our only reservations about this series are that some form of running index is needed to make the notes more readily available for reference—and of course that they are not intelligible to our own mechanics.

* Lehrbriefe für Kältetechnik. Herausgeber: Die Technischen Ausschüsse der Arbeitsgemeinschaft Kälte-Industrie. Verlag C. F. Müller, Karlsruhe.

Progress in Preventing Corrosion

MEMORIES of visits to medical museums were recalled by the sight of disease-riddled tubes at the Fifth Annual Corrosion Exhibition organized by the Society for Chemical Industry. And, in the same metaphor, prevention was the keynote. Special emphasis was placed on displays of apparatus and techniques for research and test. In a thermal load testing unit shown by the Mond Nickel Company it is possible to measure the influence of rate of heat transfer on corrosion resistance. An electric heater is placed inside a tubular metal specimen mounted in a corrosive liquid. This liquid is circulated through a cooler and the rate of heat transfer can be adjusted by varying the inlet temperature to the heating zone and the loading on the heating element. A control specimen is mounted above the test specimen to determine corrosion under conditions not involving heat transfer.

Winn and Coales Ltd. displayed anaerobic tanks for testing pipes immersed in active cultures of sulphate reducing bacteria provided in consultation with the N.C.L. Microbiology Group which is now being dispersed. Their exhibits included field test specimens exposed for twenty years with and without protective coatings.

Enthusiastic young researchers from the Manchester College of Science and Technology and the Birmingham College of Technology discussed their work on the mechanism of the protection afforded to chemical plant by sprayed coatings of aluminium, zinc and magnesium. In both cases a roughly similar basic technique was being applied. The metal was sprayed on to an insulating plastic layer which was then mounted on a steel base. By eliminating the normal electrical contact at the coating-base metal interface this permits electrical measurements during the exposures.

The Deutscher Normenausschuss has recently published another kind of contribution to this subject in the form of a four-language glossary of corrosion terms. It is a supplement to DIN 50 900 and costs 2 DM. The need for such specialised dictionaries is amusingly confirmed in the current J.R.I.C. by PROFESSOR CHALLENGER who quotes an example of a student referring to "troublesome hiccuping" in a chemical reaction in a flask. This was indeed one dictionary rendering of an original German expression but the meaning intended was "troublesome bumping."

Fluorocarbons from Coal

"IF we are ever to establish a coal-chemical industry to use coal at its present output level, the products must be something that people will burn, wear, eat or build houses with." Considered against an output of over 200m. tons per annum this comment which we heard many years ago always seemed very wise. Yet processes such as the new one for producing fluorocarbons from coal may be of value particularly in this transitional period. The British Coal Utilisation Research Association have announced that good yields of highly halogenated products are obtained by reacting a low-rank coal with gaseous chlorine trifluoride diluted with nitrogen. Approximate analysis of the chief product is C 25%, F 65%, Cl 7%. Like the perfluorocarbons the oils are thermally stable, chemically inert, non-flammable and extremely hydrophobic. BCURA suggest that they might be used as heat transfer media or hydraulic fluids while the gaseous products may be similar to the chloro-fluorocarbons used as refrigerants. A paper on the investigation was presented at the Conference on Science in the Use of Coal organised by the Institute of Fuel and now forms part of the published Proceedings (£2 10s. plus 1s. 9d. postage).

Within BCURA work is now continuing on the effects of process variables while samples are going out to interested members for appraisal. On the results of the latter will hang the decision about proceeding to the pilot-plant stage.

Recovery of Flue Dust and Mill Scale

THE steel industry has to contend with a large amount of waterborne suspended solids. Principal sources are blast furnace gas-washer water and rolling mill flume water. These settleable solids are in general recovered effectively in various kinds of sedimentation equipment. A contribution to their design has recently been made by RICHARD D.

HOAK and HENRY C. BRAMER of the Mellon Institute, Pittsburgh. After carefully defining a Sedimentation Index, they have developed an empirical equation from laboratory and field data for predicting the performance of scale pits in recovering finely divided material. The dependability of the equation is emphasised by the range it covers. Data from a long flume holding 50 gallons of water fit the equation as well as data from scale pits containing upwards of 30,000 gallons. Examples of the use of the equation, given in a paper to the American Iron and Steel Institute, show that pit depth has a significant effect on scale recovery. The importance of keeping pits clean was emphasised because accumulations of scale decrease pit depth and steadily reduce recovery efficiency.

The empirical equation has several advantages. Its use will greatly simplify surveys of scale-pit performance because it will be necessary only to plot settling rate data on influents and calculate sedimentation indexes from available physical data. An operator should now be able to schedule pit dredging on the basis of efficiency in terms of the depth of scale deposited. DRS. HOAK and BRAMER consider that they have now provided a basis for designing new pits from reasonably predictable figures for the settling rate of scale from new rolling mills. If the equation is improved with additional mill and laboratory data it will represent a real advance in the technology of mill-scale recovery.

Cycling Nuclear Fuels

A NEW approach to experimental design would be involved if the suggestions of J. C. C. STEWART and N. L. FRANKLIN were adopted for choosing optimum conditions for nuclear fuel cycles. In a paper presented to a recent symposium* the authors start from the familiar ground that nuclear power stations involve large capital investment and relatively low operating charges. Conservative operating procedures would therefore be expected but this approach is not entirely practicable because of the rapid rate of development in the field.

In the fuel cycle in particular the effective lifetime of the fuel will be determined by metallurgical and not by reactivity considerations. But the ultimate life of fuel elements from a given production route and under fixed conditions, is characterized by a distribution function. This may be crudely estimated by theoretical analysis based on small sample estimates of significant parameters. The methods of analysis can be confirmed and the approximation improved by prototype irradiation trials of fuel elements. Such results must nevertheless leave a margin of uncertainty in performance.

In consequence the reactor operator and fuel manufacturer are involved in a sequential experiment. This will necessarily be undertaken on the power reactor as the test vehicle. It has as its objective the development of a fuel cycle and a fuel age distribution within the charge which is acceptable for the preservation of the reactor. This development must secure the maximum safe irradiation lifetime from the fuel and permit the introduction and testing of new marks of fuel element as they become available.

What is so novel is that during this experiment it will be necessary to maintain reactor performance and yet undertake trials on a sufficient scale to provide statistically valid answers, not only for the irradiation life of the fuel, but also of the effect upon this lifetime of design modifications, operating conditions, and fuel handling procedures.

* Organized by the Institute of Physics in collaboration with the British Nuclear Energy Conference. Papers to be published in the Journal of the British Nuclear Energy Conference.

Alloy Composition Matters in Costing "Aluminium" Plant

Sir,

Your January, 1959, issue of *British Chemical Engineering*, as usual, makes excellent reading, but I have one or two comments to make. The article on "Capital Costs of Process Vessels, Heat Exchangers and Distillation Equipment" is very interesting, but the figures quoted for relative material costs could be misleading. It is assumed that the fabrication costs have been estimated on the basis of pure aluminium, i.e. 99.5% aluminium. However, there are many applications in chemical process plant where aluminium alloys are used. As these alloys have mechanical properties up to four times those of pure aluminium, a much more favourable relative cost figure can be obtained for "Aluminium" by efficient plant design.

I would stress, therefore, that in presenting relative material costs for process equipment, due mention should be made of the purity of the aluminium, or the specific alloy in question.

I would be obliged if my comments could be published as an open letter for the guidance of future authors.

Yours sincerely,
S. Black
British Aluminium Company Limited

MR. E. V. WOOD of Constructors John Brown Ltd.—one of the co-authors—writes: MR. S. BLACK is of course quite right in his remarks concerning the fabrication cost of aluminium vessels given in the above article. The prices are for 99.5% aluminium. It was originally intended to cover typical costs of fabricated vessels in aluminium alloys, but this had to be dropped due to lack of information at the time.

The improved mechanical properties of these alloys will result in thinner wall thickness for equal duties, and therefore reduce the cost. I am still not in a position to be able to give any figures relative to aluminium alloy fabrication but may be able to at some future date.

Solvent Extraction of Electrolytes

CYNICS may like to talk of fashions in process development but the use of organic solvents for separating inorganic materials, though fashionable, also gives practical advantages. The relevant physical chemistry deals with systems involving primarily the distribution of an electrolyte between an aqueous phase and an organic phase. In principle, each of the two phases consists of all three components, and this leads to complications. But we can choose systems, where the organic solvent is so insoluble in water, as not to influence significantly the interaction between the water and the electrolyte. This very greatly simplifies the problem, as the interactions between water and electrolytes have been studied extensively. On the other hand there appears to be no case where the water does not play a significant role in the organic phase. Discussing these systems, E. GLUECKAUF has pointed* out that solvent extraction equilibria of electrolytes in polar organic solvents are complicated by the fact that in the organic solution solvation complexes are formed which involve the electrolyte, the solvent and

the hydration water. Nevertheless experimental evidence gives a fairly clear picture of the nature of these complexes. This makes it possible to obtain explicit functions between the activities in the aqueous phase and the amounts extracted into the organic phase The paper also examines the relations between the extraction affinity and composition of the complexes as well as the effects of diluents, salting-out electrolytes and acid complexes. Specific examples are naturally connected with atomic energy—separations involving uranium, plutonium, lithium and the rare earths using such solvents at tributyl phosphate and dibutyl carbitol.

* *Industrie Chimique Belge*, 1958, XXIII, p. 1215.

Sound Methods of Measuring Flow

ALTHOUGH it is more than a twinkle in its creator's eye, the ultrasonic flowmeter is not yet an industrial product. One of the great attractions of this instrument is the promise of being able to avoid obstructions to flow within the pipes. There is no pressure drop, nor are there moving parts to corrode or clog. It should therefore meter the flow of slurries and of highly-viscous fluids, and follow the pulsations of pulsating flow. The arrangement which best meets these needs is by the mounting of transducers normal to the pipe either outside the wall or, more probably, forming a part of the wall. The basis of most of the devices so far proposed has been the modification of the apparent velocity of propagation of sound waves by the flow of the fluid. Later developments have been based on beam deflection or phase difference. R. E. FISHBACHER recently presented to the Society of Instrument Technology a survey* of the scope, limitations and design problems of a few practical versions of the ultrasonic flowmeter. Modestly, the only claim made for the instrument was that it "is likely to find a place for itself in the range of flow-measuring devices where its particular advantages are complementary to those of other types." Usable models should soon be available.

Difficulties arise however due to the effects on the ultrasonic beam of velocity profile across a pipe. Because this type of flowmeter does not inherently take account of this problem it cannot be directly calculated and will need calibration.

* To be published in the *Trans. Soc. Instr. Tech.* with the discussion.

Death from Radiation Burns

DR. THOMAS L. SHIPMAN of the University of California Los Alamos Laboratory has kindly supplied us further information about an incident during processing—reported in the general press—which unfortunately led to the death of a technician. The operation involved was the final stage in a plutonium recovery operation. For reasons which are not entirely clear, a sufficient quantity of plutonium, mostly in solution in a 225 gallon tank, somehow got in the appropriate geometry to produce a critical reaction. The worker involved was standing immediately adjacent to the tank and received a dose of radiation probably in excess of 12,000 rem. His death followed the incident by approximately 35 hours. The particular operation being carried out was essentially a standard one, but under ordinary conditions the quantities of plutonium in the tank at any one time would be so small as to preclude the possibility of such an incident. The fact is very obvious, states DR. SHIPMAN, that on this occasion the operation was carried out with too much plutonium in the tank. We understand that no relevant information is being withheld from publication and that there is now in progress a "deliberate and painstaking study" on which official reports will be issued.

Can Weathering Affect Your Plant Performance?

A REMARKABLE example of the inadequacy of short-period laboratory tests has been put forward by A. DINNIE *et al** and virtually endorsed by the Building Research Station. The moral is that long-period weathering may alter significant properties and although the detailed case concerned thermal transmittance of building materials it may well have other fields of application. Measurements were made by a guarded hotplate method of the thermal transmittance of various wall constructions under normal conditions of exposure to the weather. MR DINNIE reports that the testing, continued over a period of three winter seasons, has given new information on the thermal properties of a number of masonry constructions. This information is of immediate practical use because it takes into consideration the influence of moisture content of the masonry components. It is at variance with existing information on the thermal properties of building materials. Examples are the U-value of an 11 in. cavity Fletton brick wall normally given as 0.30 which was measured as 0.28 and the thermal conductivity of a 4 in. cellular concrete block inner leaf published as 1.4 which was found to be 1.85. The authors comment that insufficient attention has previously been paid to the fact that conductivity of a material varies considerably in practice with its moisture content, which in turn depends on the position of the material in use. The value will differ if it forms an inner or outer leaf of a cavity wall. Failure to recognize this fact is the reason why U values calculated on the basis of present published information for building materials can be completely unrealistic.

Will this set readers checking over the state of any exterior badly applied lagging or electric tracing cables?

* Paper presented before British Ceramic Society Building Materials Section.

Adsorptive Purification of Liquid Oxygen

FEW basic data directly applicable to process design or to performance evaluation of low temperature adsorbers have been made public. New ground has therefore been broken by A. C. T. HSU and CLYDE MCKINLEY in their paper* on adsorptive purification of liquid oxygen. The authors examined the significance of pressure, concentration, nature of contaminants, and especially the influence of adsorbates upon each other during simultaneous adsorption. All of this was carried out with solutions of methane, ethane, and ethylene in oxygen under actual process conditions such as prevail in crude liquid oxygen adsorbers. The adsorbent was silica gel. Results confirmed, as would be expected, that this adsorbent has a much higher capacity for ethylene than for ethane. It was also found to have an extremely low capacity for methane, which would be readily displaced by other hydrocarbons occurring in normal crude liquid oxygen. Another finding was that there was essentially no difference in the amount of ethylene adsorbed by silica gel whether the olefin was carried in liquid oxygen or in a liquid mixture of 40% oxygen—60% nitrogen.

As long as the carrier fluid—either oxygen or 40% oxygen—60% nitrogen—remained as liquid, variation of pressure between 45 and 135 psia had no appreciable effect on the adsorption of ethane and ethylene by silica gel. This generalization was thought to apply to other hydrocarbons in crude oxygen so that there should be no shift of adsorbate distribution on silica gel in the event of minor pressure fluctuations inside hydrocarbon adsorbers. Data are presented both as Freundlich-type graphs and as equations.

* Presented at Low Pressure Processing Symposium, American Institute of Chemical Engineers, 1958.

British Chemical Engineering
A HEYWOOD PUBLICATION

Heat Transfer—a Field for Economy

OUR new contents page, now removed to a position where it will meet the reader's eye more readily, with its translated summaries for the benefit of our overseas readers, marks the first issue of this journal to devoting its main articles in their entirety to a single subject of chemical engineering. The subject of our choice, heat transfer, has throughout man's history played a commanding role in the development of his productive resources, and is today of controlling importance in the design and operation of a vast array of industrial equipment ranging from massive nuclear power generators at one end of the scale to the steam jacketed kettle at the other. It is a subject which is the concern of many branches of engineering and one with which few major advances in technology have not in some way or other been connected.

The scientific history of heat transfer, opening less than two centuries ago, owes its genesis without doubt to NEWTON who in 1701 advanced his simple law of cooling. And if in our day this law is no longer used in the form in which he presented it, it still plays a useful role in the teaching of physics. From the time of NEWTON'S law a century passed before BROT presented his conduction equation and FOURIER, for his part, his treatise on the same subject. At the approach of the present century OSBORNE REYNOLDS proposed his famous analogy between momentum and heat transfer. Then followed in rapid succession a number of important laws covering various parts of the field, whose separate mechanisms were by now recognised. Thus there appeared STEFAN'S radiation law, LORENTZ'S theory of laminar flow natural-convection and GRAETY'S treatment of laminar flow heat transfer. Thereafter the tempo of advance rapidly increased.

To appreciate the present-day level of best heat-transfer practice, we can do no better than to hark back to one of the earliest text-books on chemical engineering—DAVIS'S celebrated handbook. In this he proposes, for the design of steam jackets, a very simple rule which amounts to taking a square foot of heating surface for raising so many gallons of water a certain number of degrees in a given time, using steam at a specified pressure as the source of heat. In this field nowadays our approach would make use of the ECKERT relationship and it is interesting to note that DAVIS failed to take advantage of the work of LORENTZ which appeared some twenty years earlier. But in those days the gap between discovery and use was greater than it is now. So far has progress taken us that today we have at our disposal a remarkable array of equations and procedures, covering many sides of the subject, which can be applied successfully to industrial problems. We can now make use of digital and analogue computation to render soluble problems which were in the past considered untractable.

It cannot be denied that in equipment design there have been many outstanding achievements, such as the numerous types of compact and extended surfaces and the exchangers which make use of them. These are to be found in a diversity of fields including nuclear power at one extreme and low-temperature gas separation at the other. Moreover, the air-cooled exchanger, a major application for extended surfaces, offers a valuable alternative solution to the problem of cooling water shortage. But despite all this, it is doubtful whether commercial apparatus has consistently kept pace with the science, for in some branches of industry antiquated designs are still in evidence, and design procedures exist which are little more than marginal improvements upon DAVIS'S rough and ready rule. Tending no doubt to perpetuate these survivals is an apathy in industry to a theoretical approach to plant performance data, coupled to an unwarranted confidence in empiricism. In cases of failure of a particular exchanger to attain its specified performance, this state of affairs has led to many bitter disputes between the user and the designer-fabricator. All too readily one party or the other attributes the failure to fouling. Indeed, few practices can have made for as much unnecessary expense in heat-exchange equipment as the conventional use of fouling factors. This underlines a serious weakness in the literature of heat transfer and the amount devoted to the matter is about inversely proportional to its importance. Originally the fouling factors which appeared in the "Standards of the Tubular Exchanger Manufacturers' Association", and elsewhere, were intended to secure a period of operation for an exchanger before dirt reduced its performance below a desired level. Unfortunately, these factors have no reference to time; no one can say, for example, how long in given circumstances a unit of fouling factor will last. In reality, these factors, which are arbitrary and bear little real relation to performance, are a means of making exchangers larger than they need be were their surfaces to remain clean.

To their conventional use there are a number of objections. As has been pointed out in these columns, fouling need not always lead to poorer performance and the use of these factors sometimes produces an effect the reverse of that intended. That most practical of heat-transfer specialists, DONALD Q. KERN, has recently pointed out that if through ignorance of its true value an excessive fouling factor is chosen it may well lead to an increase of fouling and a diminution in the running time. To the cost of the extra surface now has to be added the loss of production and the cost of greater maintenance. Here, then, is a section of this vast subject which calls out for serious treatment in order that cheaper designs can be evolved.

Thermal design is not the only area where economies can be made. Details of mechanical design, including flanges and tube plates, have, in many cases, seemed unnecessarily massive. It is welcome news that the new edition of B.S. 1500, following the work of LAKE, offers a much lighter flange than the widely used TAYLOR-FORGE procedure. Another welcome sign is the proposal to take into account the supporting effect of tubes upon tube plates. This, too, holds promise of significant economies.

66.045.2—97

HEAT-TRANSFER CHARTS FOR TIME-VARIABLE BOUNDARY CONDITIONS — SEMI-INFINITE SOLID

by TAGHI J. MIRSEPASSI, Ph.D.

Charts are presented for the solution of the general problems of (a) determining temperature in a semi-infinite solid when the boundary temperature (or flux per unit area per unit time) is an arbitrarily plotted function of time, and (b) determining an unknown boundary temperature (or flux per unit area per unit time) from a given temperature recording of a point in the solid.

IN heat-conduction studies, the evaluation of an analytical solution is often a lengthy process. Each evaluation may require finding the roots of a transcendental equation, using special mathematical tables, and computing many terms of a series. Because of this complexity, many authors have computed, either by direct calculation or by analogue experiments, the numerical values of certain analytical solutions and have presented the results graphically. The tasks have well served the purpose and have made possible the rapid solution of many problems.

There are, however, numerous other complicated analytical expressions that, although of great practical application, have not yet been worked out for a quick, easy and accurate graphical evaluation. DUHAMEL'S solution[1, 2] is one of them. This solution (first published in 1832) determines analytically the temperatures in a solid when the boundary temperature varies with time. The solution, representing a very realistic condition, has numerous technical applications in engineering heat transfer.

In the evaluation of DUHAMEL'S expression, two kinds of difficulty are involved: (a) those due to the usual complexity of solution of transient conduction problems and (b) those due to the additional complexity introduced by the integral form of DUHAMEL'S formula. Since the boundary-temperature function is present in the integrand of DUHAMEL'S expression, preparation of a temperature-time chart by the existing methods is only possible after assuming some function (e.g., linear, exponential, sinusoidal, etc.) for the time-variable boundary temperature. Such a chart will not serve for the solution of the more general and practical problem of "determining temperature in a solid when the boundary temperature is an arbitrarily plotted function of time" or for "determining an unknown boundary temperature from a given temperature-time recording of a point in the solid".

The purpose of this report is twofold: (a) the presentation of charts for the solution of these heat-transfer problems, and (b) the introduction of a new concept in computational charts for other possible applications (e.g., the solution of integral equations). Although the charts presented here theoretically apply only to the semi-infinite solid, practically they can be used as well for the early times for the regions near the surface of other configurations. Charts for intermediate and longer times of other configurations are under preparation and will be published as completed.

Dr. Mirsepassi *is Head of the Heat and Mass Flow Laboratory, Corporate Research Operation, Aerojet-General Corp., Azusa, California.*

Symbols Used

x = distance from surface of semi-infinite solid;
θ = time;
t_s or $t_s(\theta)$ = surface temperature at time θ;
t_x or $t(x, \theta)$ = temperature at x, at time θ;
t_{in} = initial temperature;
t_o = a constant temperature;
T_i = average value of $(t_s - t_{in})/(t_o - t_{in})$ in time interval $i\triangle\theta$ $(i = 1, 2, \ldots)$;
f_s or $f(\theta)$ = surface heat flux per unit area per unit time θ;
F_o = a constant heat flux per unit area per unit time;
F_i = average value of $f(\theta)/F_o$ in time interval $i\triangle\theta$;
a = thermal diffusivity; and
K = thermal conductivity.

Charts

The charts shown in Figs. 1a, 1b and 1c are for problems with time-variable surface temperature and cover the following ranges of the dimensionless time, $\Theta = 4a\theta/x^2$:

Figure	*Range of*	*In Intervals of*
1a	0.02 - 0.80	0.02
1b	0.2 - 0.8	0.2
1c	2.0 - 80.0	2.0

The chart presented in Fig. 2 is for problems with time-variable surface flux per unit area per unit time. The dimensionless time

$$\Theta = \theta/\theta_o$$

has been introduced where θ_o is an arbitrary time to be selected in such a manner that Θ falls within the range of the chart, i.e., 0.02-0.80.

The numbers written on top of each chart under the heading G_i have been computed from the following equation for Figs 1a, 1b and 1c:

$$G_i = erf.\ \frac{1}{\sqrt{(i-1)\ \triangle\Theta}} - erf.\ \frac{1}{\sqrt{i\triangle\Theta}},\ (i = 1, 2, \ldots) \qquad \ldots.(1)$$

For Fig. 2 the following equation has been used:

$$G_i = \sqrt{i\triangle\Theta} - \sqrt{(i-1)\ \triangle\Theta} \qquad \ldots.(2)$$

These values are useful for direct numerical evaluation, i.e., without graphical use of the charts, by means of the finite difference equations. For variable surface temperature the following applies:

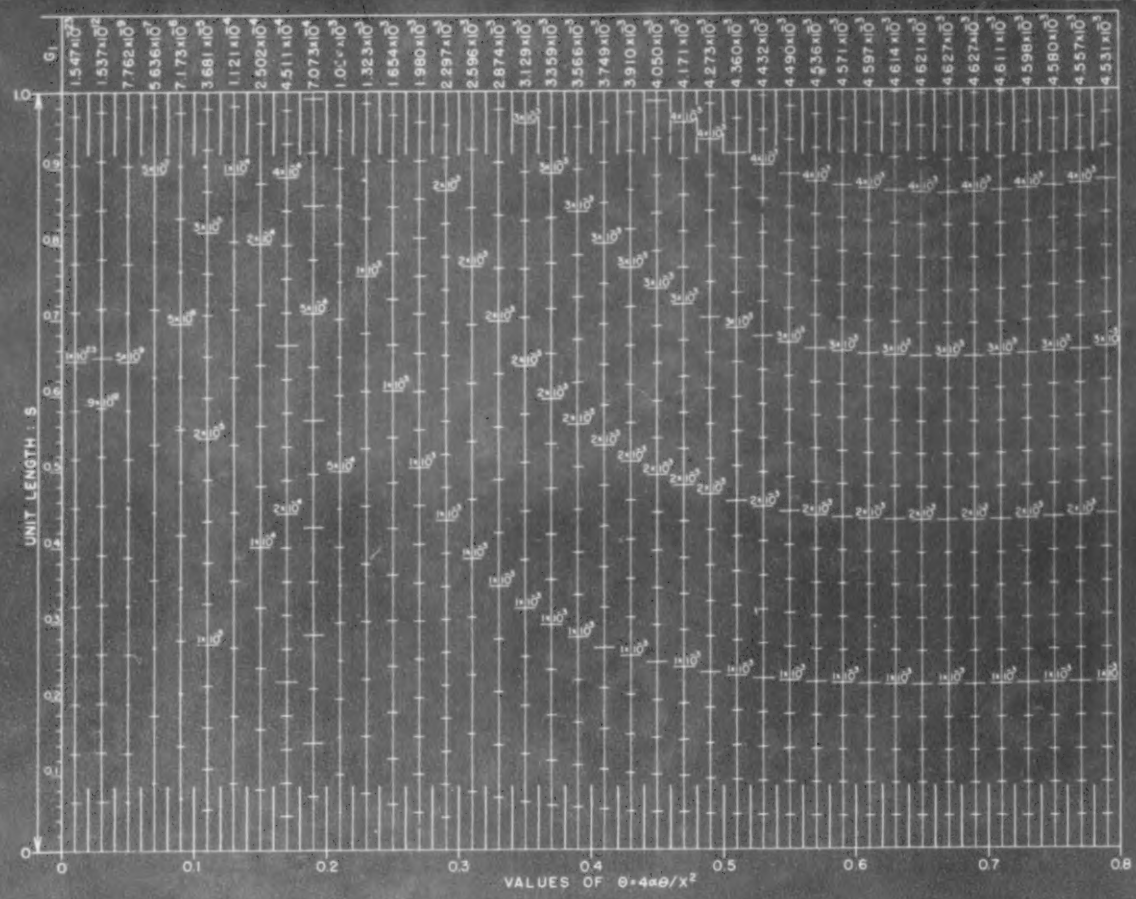
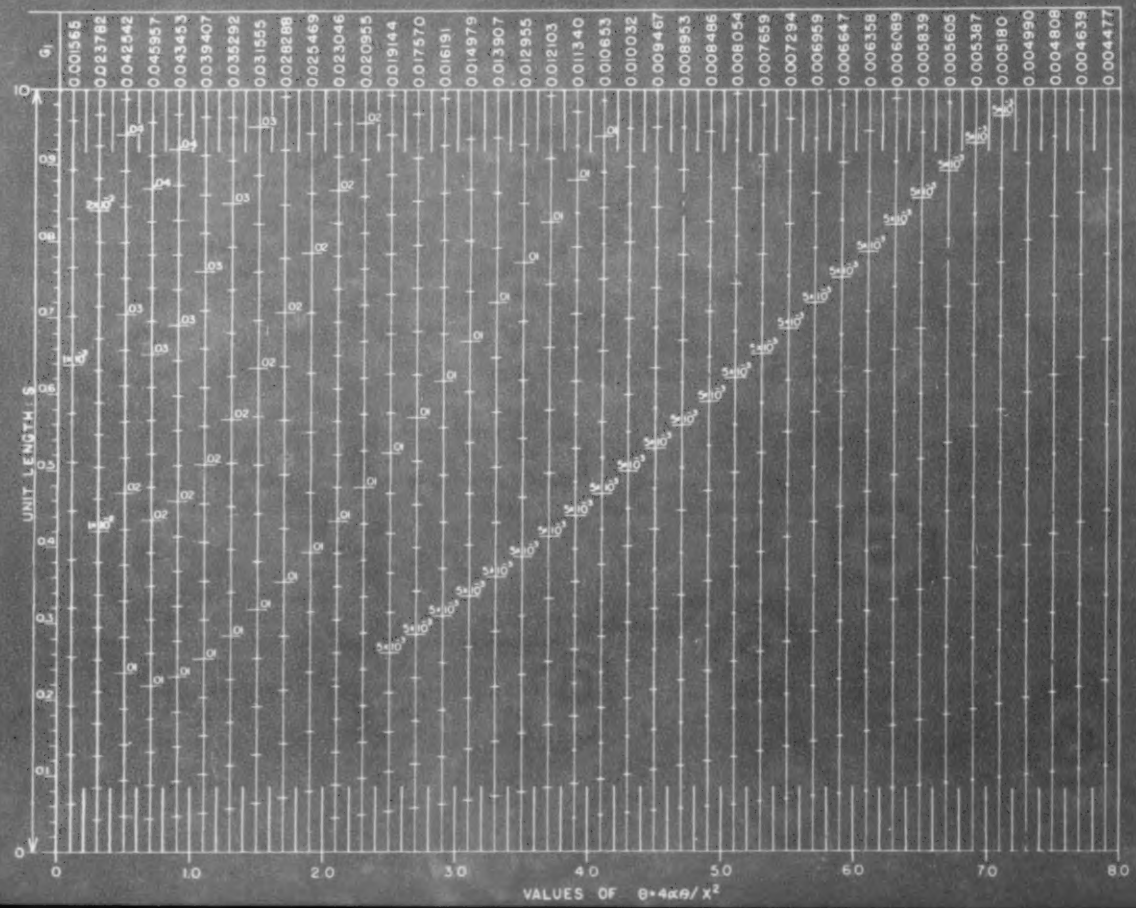


Fig. 1*a* (*above*). *Heat-transfer chart for variable-surface temperature, semi-infinite solid for dimensionless times* 0.02 *to* 0.80.

Fig. 1*b* (*below*). *Heat-transfer chart for variable-surface temperature, semi-infinite solid, for dimensionless times* 0.2 *to* 8.0.



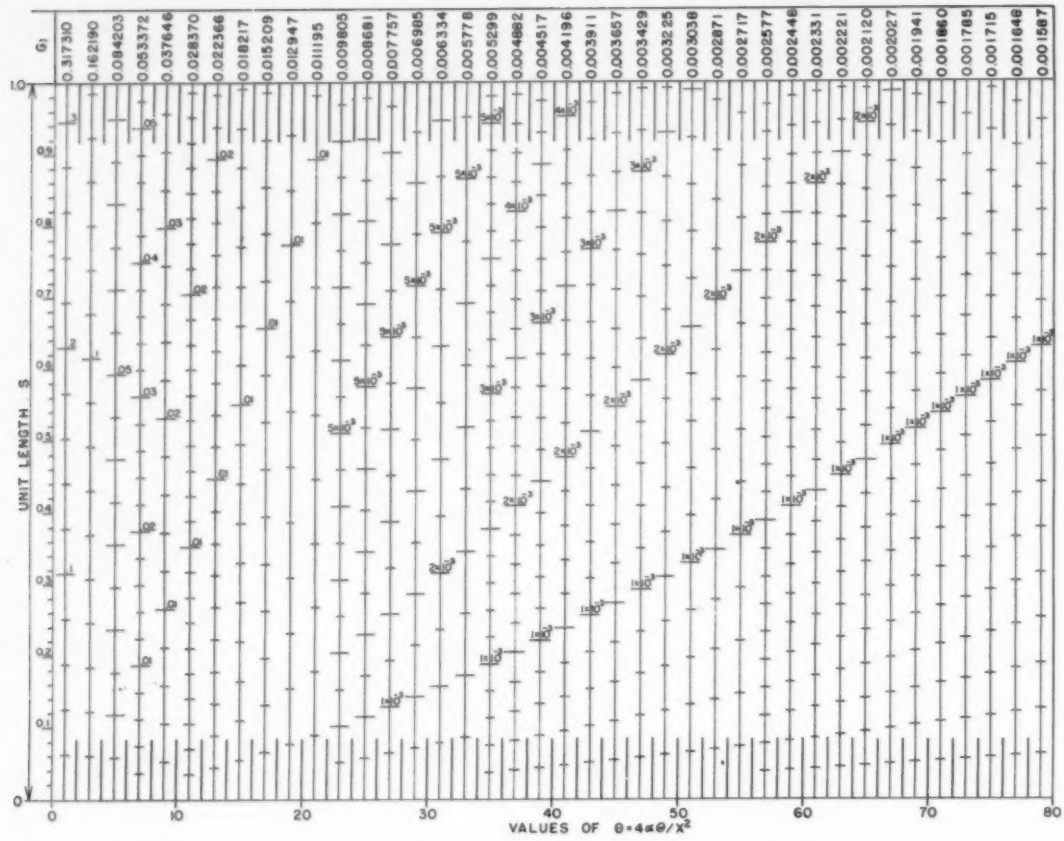


Fig. 1c. *Heat-transfer chart for variable-surface temperature, semi-infinite solid, for dimensionless times* 2 *to* 80.

$$\frac{t\,(x, n\triangle\theta) - t_{in}}{t_o - t_{in}} = \sum_{i=1}^{i=n} T_{n-i+1} \cdot G_i \qquad \ldots . (3)$$

Variable surface flux per unit area per unit time is evaluated by the following equation:

$$\frac{t_s\,(\theta) - t_{in}}{F_o} \cdot \frac{K.\sqrt{\pi}}{2\sqrt{\alpha\theta_o}} = \sum_{i=1}^{i=n} F_{n-i+1} \cdot G_i \ldots . (4)$$

The basic technique and method of construction of the charts are described elsewhere.*

Examples

(A) Example 1—(1) *Problem*

The surface temperature, t_s, in a semi-infinite solid, initially at temperature t_{in}, varies with time, θ, as shown in Fig. 3a, by the plotting of:

$$\frac{t_s - t_{in}}{t_o - t_{in}} \text{ where } t_o = 1070°\text{F},\ t_{in} = 70°\text{F}$$

Determine the temperature-time history at a point 1 in. below the surface ($x = 1$ in.) during the first 2 hours. Assume $\alpha = 0.04167$ ft²/hr.

(2) *Solution*

(a) Since the dimensionless time duration of interest is

$$\Theta = \frac{4\alpha\theta}{x^2} = \frac{4 \times 0.04167 \times 2}{(1/12)^2} = 48$$

Fig. 1c is to be used. Each interval $\triangle\Theta = 2$ in this chart represents, for the point $x = 1$ in., an actual time of:

$$\triangle\theta = \frac{\triangle\Theta \times x^2}{4\alpha} = 5 \text{ min.}$$

(b) Replot Fig. 3a with the scale along the θ axis as in the chart (i.e., the distance between centre lines equal to 5 min.) and the scale along the ordinate equal to the unit length, S. Take the θ axis increasing to the left (see Fig. 3b, which should be drawn on transparent paper).

(c) Superimpose Fig. 3b on Fig. 1c (as shown in Fig. 3c for evaluation at $\theta = 30$ min.) and add the readings at the intersections of the curve and the graduated centre lines in the chart; thus, for $\theta = 30$ min. (Fig. 3c)

$$\frac{t_x - t_{in}}{t_o - t_{in}} =$$

$$0.013 + 0.020 + 0.032 + 0.057 + 0.120 + 0.260 = 0.502$$

and locate point P in Fig. 3d.

(d) Repeat step (c) for other values of θ. The result is plotted in Fig. 3d, where the function $(t_s - t_{in})/(t_o - t_{in})$ is also shown as a broken line.

(B) Example 2—(1) *Problem*

In an experiment aimed at determining the variation of heat-transfer coefficient on vertical surfaces in early times of quenching, a large slab was preheated to a uniform temperature of $t_{in} = 1500°$F and then instantly submerged in quiescent water, and the temperature-time history, t_z, at a point very far from the corners and 0.035 ft below the surface ($x = 0.035$ ft) was recorded (see Fig. 4a). Determine the temperature-time history, t_s, of the slab. Assume $\alpha = 7.35$ sq. ft/hr.

* Aerojet-General Corporation, Azusa, California. Special Report No. 1375.

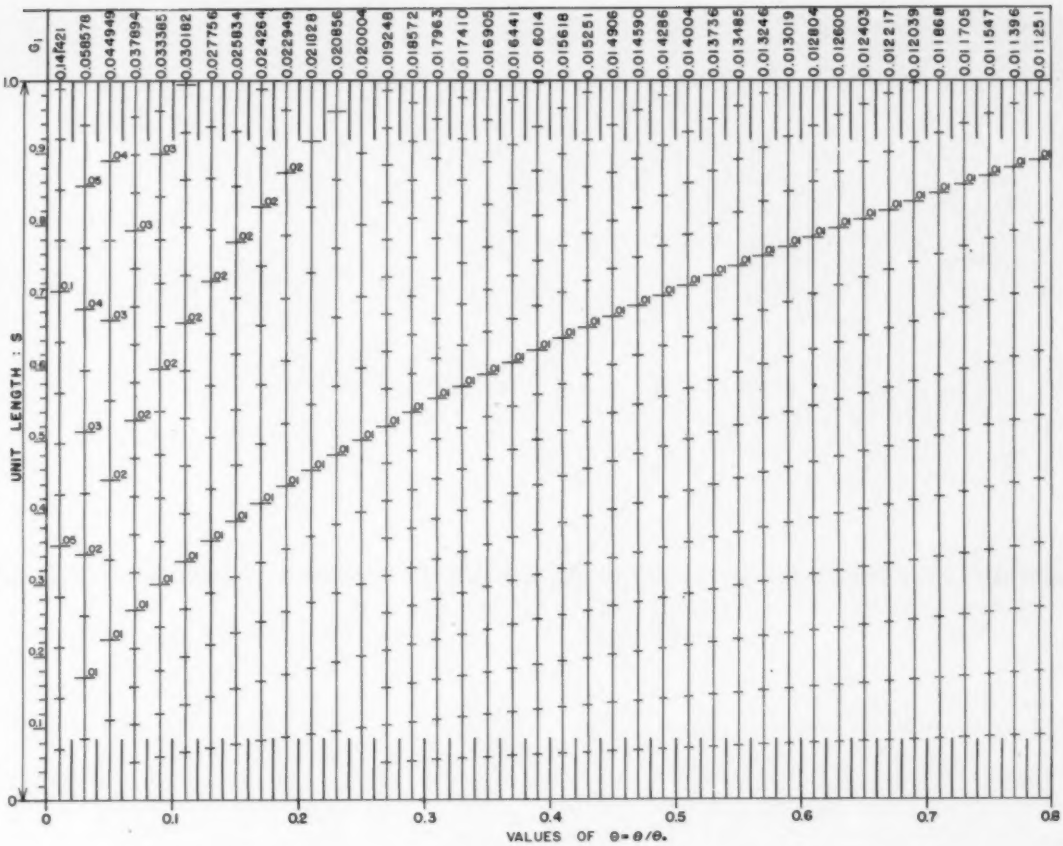


Fig. 2. Heat-transfer chart for variable-surface flux per unit area per unit time, semi-infinite solid.

(2) *Solution*

(a) The longest time in Fig. 4a is 8 sec., which corresponds to a dimensionless time of:

$$\Theta = \frac{4\alpha\theta}{x^2} = \frac{4 \times 7.35 \times 8}{(0.035)^2 \times 3600} = 53.3$$

Therefore, Fig. 1c is to be used. Each interval $\triangle\,\Theta = 2$ in this chart represents, for the point $x = 0.035$ ft, an actual time of

$$\triangle\theta = \frac{\triangle\Theta \times x^2}{4\alpha} = \frac{2 \times (0.035)^2}{4 \times 7.35} \text{ hr} = 0.3 \text{ sec.}$$

(b) From Fig. 4a, plot the function

$$(t_x - t_{in})/(t_o - t_{in}),\ (t_o = 1000°\text{F})$$

with the θ axis increasing from right to left and a scale the same as in the chart (i.e., the distance between centre lines representing 0.3 sec.) and the scale along the ordinate equal to the unit length S. (See Fig. 4b, which should be drawn on transparent paper.)

(c) Superimpose Fig. 4b on Fig. 1c, as shown in enlarged view in Fig. 4c. Let A denote the intersection of the unknown $(t_s - t_{in})/(t_o - t_{in})$ with the centre line. From Equation (3) written for $n = i = 1$:

$$\frac{t(x,\ \triangle\theta) - t_{in}}{t_o - t_{in}} = T_1 \,.\, G_1$$

The left side of this equation is the reading at P from the graduated unit scale, while the right side is the reading at A from the graduated centre line; the left side being known (e.g., 0.05 in Fig. 4c), the right side and consequently the location of point A is determined (e.g., in Fig. 4c, it is where the reading along the centre line is 0.05). Then slide Fig. 4b on the chart to the second position, as shown in Fig. 4d. Let B denote the new intersection of $(t_s - t_{in})/(t_o - t_{in})$ and the first centre line. From Equation (3) written for $n = 2$:

$$\frac{t(x,\ 2\triangle\theta) - t_{in}}{t_o - t_{in}} = T_2 \,.\, G_1 + T_1 \,.\, G_2$$

Since

$T_1 \,.\, G_2$ = reading at A from graduated centre line (i.e., 0.0255 in Fig. 4c) and

$[t(x,\ 2\triangle\theta) - t_{in}]/(t_o - t_{in})$ = reading at Q from graduated unit scale (i.e., 0.114 in Fig. 4c)

therefore

$T_2 \,.\, G_1$ = reading at B from graduated centre line

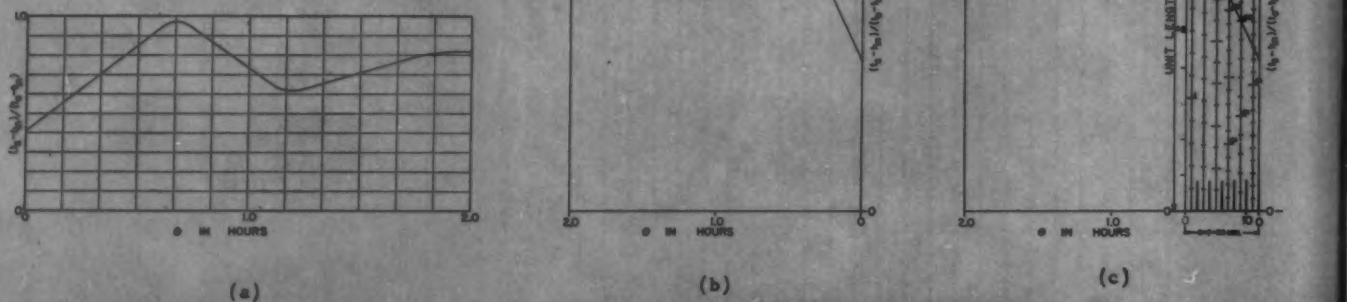
$$= \frac{t(x,\ 2\triangle\theta) - t_{in}}{t_o - t_{in}} - T_1 \,.\, G_2 = 0.114 - 0.0255 = 0.0885$$

and in Fig. 4d point B is located where the reading along the centre line is 0.088. Thus, after each sliding, the reading at the new intersection of $(t_s - t_{in})/(t_o - t_{in})$ and the first centre line is obtained by subtracting from $[t(x,\ n\triangle\theta) - t_{in}]/(t_o - t_{in})$ (read from graduated unit scale) the sum of the readings at A, B, . . ., etc., and consequently the new intersection is located. In Fig. 4e the final result is shown where a temperature scale, added to the left of the drawing, serves to read t_s directly in °F.

(C) EXAMPLE 3—(1) *Problem*

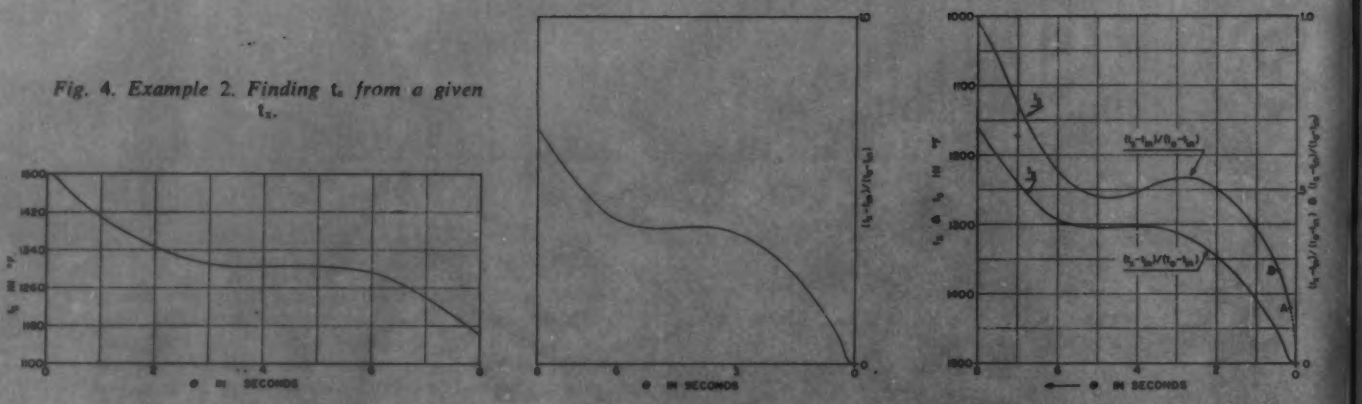
A variable heat flux, $f(\theta)$, as shown in Fig. 5a, where $F_o = 2 \times 10^6$ Btu/sq. ft hr, is applied to the surface of a

Fig. 3. Example 1. Finding $(t_x - t_{in})/(t_o - t_{in})$ *from a given* $(t_e - t_{in})/(t_o - t_{in})$.



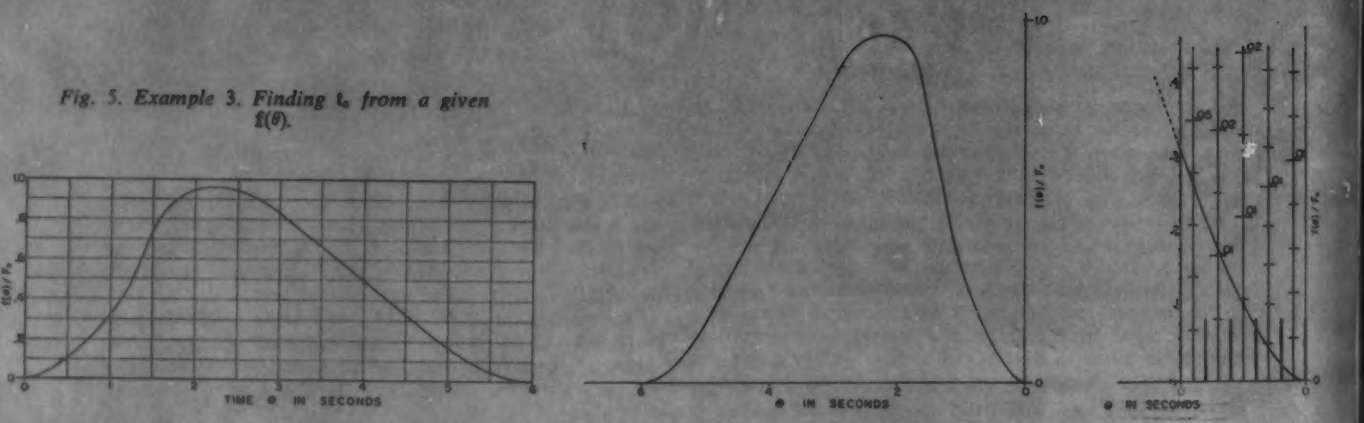
(a) (b) (c)

Fig. 4. Example 2. Finding t_o *from a given* t_x.

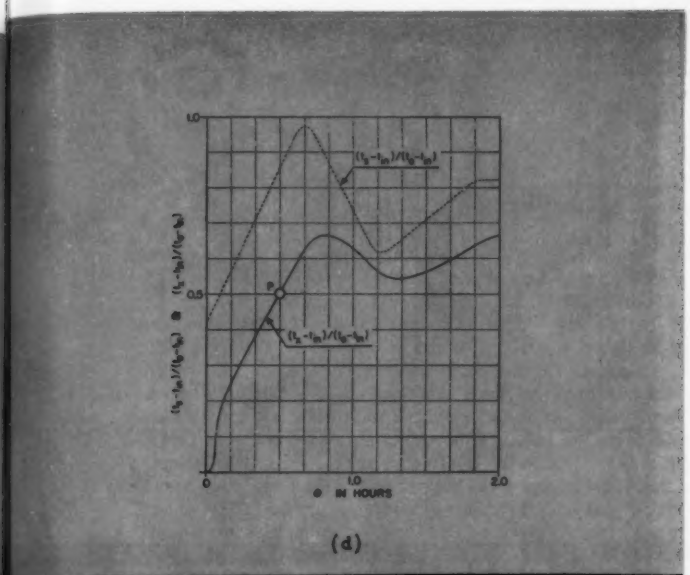


(a) (b) (c)

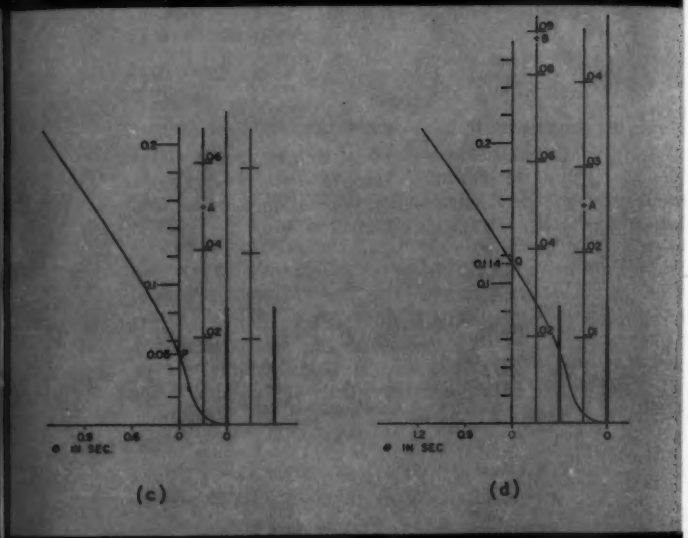
Fig. 5. Example 3. Finding t_o *from a given* $f(\theta)$.



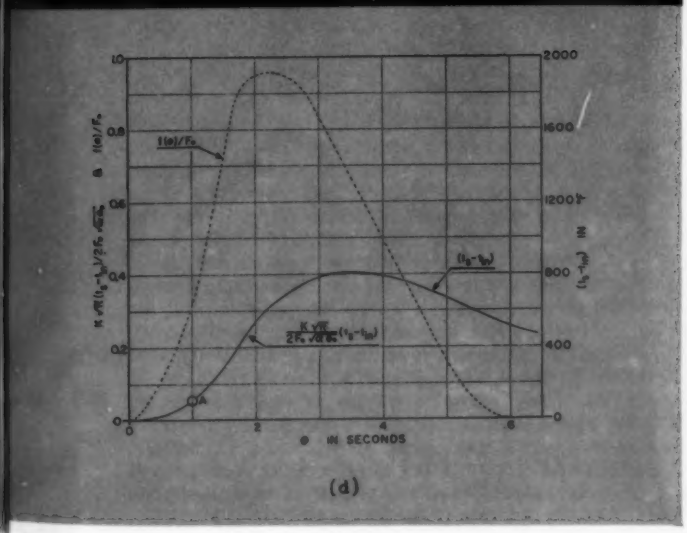
(a) (b) (c)



(d)



(c) (d)



(d)

semi-infinite solid ($K = 32$ Btu/sq. ft, hr °F/ft, $\alpha = 0.29$ sq. ft/hr). Determine the surface temperature during the first 6 sec.

(2) *Solution*

(a) θ_o must be so selected that θ_1/θ_o falls within the range of Chart 2; i.e.,

$$(\theta_1/\theta_o) < 0.8 \qquad \ldots . (5)$$

Let $\theta_1 = 6$ sec. and, in order to keep the corresponding dimensionless time, Θ, within the range of Fig. 2, select:

$$\theta_1/\theta_o = 0.6$$

Thus, $\theta_o = 10$ sec., and each interval

$$\Delta\,\Theta = 0.02$$

in the chart represents an actual time of

$$\theta = 10 \times 0.02 = 0.2 \text{ sec.}$$

With the above scale for θ, and unit length for the scale of ordinates, replot Fig. 5a, taking the θ axis to the left (see Fig. 5b).

(b) Superimpose Fig. 5b on Chart 2, as shown in enlarged view in Fig. 5c, for evaluation of

$$\frac{K \cdot \sqrt{\pi}}{2F_o \cdot \sqrt{\alpha\theta_o}}\,(t_s - t_{in})$$

at $\theta = 1$ sec., and add the readings at the intersection of the curve and the graduated centre lines. Thus for $\theta = 1$ sec. (Fig. 5c):

$$\frac{K \cdot \sqrt{\pi}}{2F_o \cdot \sqrt{\alpha\theta_o}}\,(t_s - t_{in}) =$$

$$0.0002 + 0.0018 + 0.0047 + 0.0105 + 0.0375 = 0.0547$$

locate point A in Fig. 5d.

Repeat step (b) for other values of θ. The curve drawn as a solid line in Fig. 5d shows the final result. The dotted line represents $f(\theta)/F_o$, and the temperature scale on the right of the figure serves to determine $(t_s - t_{in})$ directly in °F. The conversion factor used for this purpose is

$$\frac{2F_o \cdot \sqrt{\alpha\theta_o}}{K \cdot \sqrt{\pi}} = \frac{2 \times 2 \times 10^6 \sqrt{0.29 \times (10/3600)}}{32\sqrt{\pi}}$$

$$= 2000\text{°F.}$$

(D) EXAMPLE 4—(1) *Problem*

For conditions as in Example 2, determine the surface flux, f_s, per unit area per unit time. Assume $K = 198$Btu/sq. ft. hr °F/ft.

(2) *Solution*

(a) In Equation (5) let $\theta_1 = 9$ sec., and

$$\theta_1/\theta_o = 0.6.$$

Thus, $\theta_o = 15$ sec., and each interval

$$\Delta\,\Theta = 0.02$$

in Fig. 2 represents an actual time of

$$\Delta\theta = 15 \times 0.02 = 0.3 \text{ sec.}$$

With the above scale for θ, and unit length for the scale of ordinates, plot the function

$$\frac{K \cdot \sqrt{\pi}}{2F_o \cdot \sqrt{\alpha\theta_o}}\,(t_s - t_{in}) \text{ against } \theta$$

and take the θ axis to the left, Fig. 6a.

The value for F_o has been chosen, arbitrarily, such that

$$\frac{2F_o \cdot \sqrt{\alpha\theta_o}}{K \cdot \sqrt{\pi}} = -1000, \quad (F_o = -1 \times 10^6 \text{ Btu/sq. ft, hr})$$

(b) Superimpose Fig. 6a on the chart, as shown in Fig. 6b. Let A denote the intersection of the unknown $f(\theta)/F_o$ with the centre line; then, from Equation (4), written for $n = i = 1$

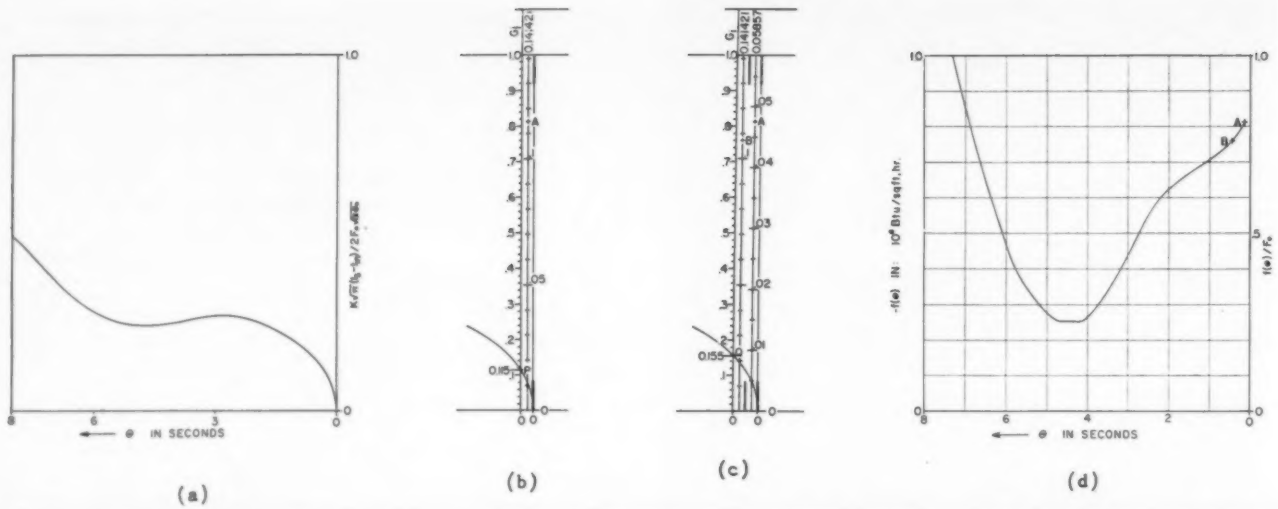


Fig. 6. Example 4. Finding f(θ) from a given t_s.

$$\frac{K.\sqrt{\pi}}{2F_o.\sqrt{\alpha\theta_o}}(t_s - t_{in}) = F_1 \,.\, G_1.$$

The left side of this equation is the reading at P from the graduated unit scale (which is 0.115 in Fig. 6b), while the right side is the reading at A from the graduated centre line; thus, in Fig. 6b, point A is where the reading along the centre line is 0.115. Then slide Fig. 6b on the chart to the second position, as shown in Fig. 6c. Let B denote the new intersection of $f(\theta)/F_o$ and the first centre line; then, from Equation (4) written for $n = 2$:

$$\frac{K\,.\,\sqrt{\pi}}{2F_o\,.\,\sqrt{\alpha\theta_o}}(t_s - t_{in}) = F_2\,.\,G_1 + F_1\,.\,G_2$$

Since

$F_1 \,.\, G_2$ = reading at A from graduated centre line (i.e., 0.0475 in Fig. 6c)

$\frac{K\,.\,\sqrt{\pi}}{2F_o\,.\,\sqrt{\alpha\theta_o}}(t_s - t_{in})$ = reading at Q from graduated unit scale (i.e., 0.155 in , Fig. 6c.)

therefore

$$F_2\,.\,G_1 = \frac{K\,.\,\sqrt{\pi}}{2F_o\,.\,\sqrt{\alpha\theta_o}}(t_s - t_{in}) - F_1\,.\,G_2 = 0.155 - 0.0475 = 0.1075$$

= reading at B from graduated centre line

and in Fig. 6c point B is located where the reading along the first centre line is 0.1075. Thus, after each sliding, the reading at the new intersection of $f(\theta)/F_o$ and the first centre line is obtained by subtracting from

$$\frac{K\,.\,\sqrt{\pi}}{2F_o\,.\,\sqrt{\alpha\theta_o}}\left[t_s\,(n\triangle\theta) - t_{in}\right]$$

(read from graduated unit scale), the sum of the readings at A, B, . . ., etc., and, consequently, the new intersection is located. In Fig. 6d the final result is shown where a scale for "flux per unit area per unit time" is added to the left of the drawing and serves to read $f(\theta)$ directly in Btu/sq. ft hr.

REFERENCES

[1] Carslaw, H. S., and Jaeger, J. C. "Conduction of Heat in Solids", Oxford University Press, 1947, pp. 19-22, 43, 56-57.

[2] Schneider, P. J. "Conduction Heat Transfer", Addison-Wesley Publishing Co. Inc., Cambridge, Mass., 1955, p. 272.

[3] National Bureau of Standards. "Table of the Error Function and Its Derivative", U.S. Department of Commerce, Applied Mathematics Series No. 41.

World's Biggest Drum-Malting Plant

A BOX-DRUM malting plant having a capacity of 450 tons of barley-in-process a day and claimed to be the biggest in the world, has just been commissioned by Bass, Ratcliff & Gretton Ltd., Burton-on-Trent.

It was designed to allow malting to proceed throughout the whole year uniformly, independent of weather and with a minimum of manual work. Instrumentation and mechanical handling is therefore a special feature of it and a novelty in its design is that the whole process of steeping, germinating and kilning can be controlled from a central instruments deck. Main contractors for the installation, costing over £600,000, were Robert Boby Ltd.

The plant for the germinating process contains ten box drums of mild-steel plate 47 ft between end plates and 12 ft in diameter and providing a volume of 5300 cu. ft. Each weighs 28 tons empty and 64 tons loaded, and is powered by a 7½-hp motor which turns the drum at the rate of one revolution every 20 min. The depth of steeped grain when first loaded is 38 in., and the average length of time the malt remains in the drums is nine days.

Each drum is provided with a control panel This accommodates a temperature indicator light controlled by a 5-ft-long spear thermometer which is dipped into the grain in the drum when a reading is required. A second light shows green when the air conditioning is running and a third light shows amber when the conditioner spray pump fails. The panel also carries an air-damper indicator, air volume damper indicator, and ammeters for the spray pump and the fan. Spray water-pressure and air-on and air-off temperatures are also shown.

The four kilns, whose floors are of fine wire wedge, may be loaded with the help of a mechanical conveyor in 4 hours and the malt turned in 20 min. by a mild-steel turning plough. Each kiln has a temperature recorder and a light that indicates when the kiln air temperature rises more than 1°F above a predetermined value.

FIBRE FILTERS FOR FINE ACID MIST

TERYLENE fibres formed into a pad 2 in. thick are reported to form a virtually perfect filter for fine particles of sulphuric acid mist. The high efficiency of the filter action is thought to be due to the fine diameter of the fibres and their hydrophobic character which results in dropwise collection of fine liquid particles. Elements based on this type of pad may be pre-formed into candles or flat discs. A similar effect may also be produced by glass fibres treated with a silicone such as I.C.I. silicone M441. In the latter case, the pad is pre-formed at a temperature in the range 400°C to 550°C, while for the Terylene the effective temperature is in the range 140°C to 160°C. Forming involves compressing, stress relief and final heating to set the pad into the desired shape. It is important to maintain evenness during the manufacture of the pad in order to avoid channelling.

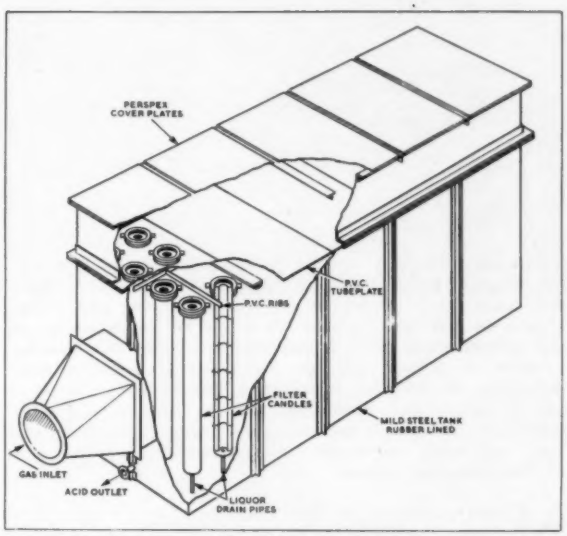
An extensive programme of research by MR. G. LOWRIE FAIRS, of I.C.I. General Chemicals Division, forms the basis for this invention which is the subject of patent application by Plaut and Fairs in this country and elsewhere. Rights for sales in Great Britain are held by Mancuna Engineering Ltd. and Nordac Ltd., who, together with I.C.I., are carrying out the engineering design needed for building practical units based on this research. The published work* is based largely on experience with silicone-treated glass fibre, a few data also being given for garneted Terylene fibre. Present developments, however, by Mancuna Ltd., are based on the use of staple Terylene fibres. When the pilot plants are in operation it is intended to carry out further research on applications. Mancuna have stated that this will include the study of mists of hydrofluoric acid and phosphorus pentoxide and also the further development of irrigated filters.

Main Application of Filters

The main application of the filters as at present developed is for sulphuric acid. The mist is sampled and its particle size distribution determined in order to decide on the packing density. This means that operators have to be trained in sampling using iso-kinetic techniques. The mist is then collected in a sample settling chamber and the size distribution of the mist is then determined by a microscope.

It is announced that the filter is self-compensating over a wide range of gas-flow rate and mist loading. If the acid droplets are likely to attack the Terylene fibres or the silicone surface of the glass wool, the gas must be passed through a humidification unit to dilute the acid. On starting up a filter, a period of up to 24 hours is required before reaching maximum efficiency, since it is necessary to build-up an equilibrium hold-up of liquor in the filter bed. After this initial period there is no further build-up and the filter is self-draining. The fibre diameters range from 5 to 50 microns, but it is understood that effective operation depends on the correct choice of distribution of these diameters.

In one design units are being assembled in blocks of standard filters, each consisting of 6 × 10-in. candle elements sealed together end-to-end to form a filter candle. Including its support frame, the unit will stand about 6 ft high and will require 13 ft headroom to allow for withdrawal for servicing. Several separate units, each of 40 candles, will be connected in parallel to a common header which is higher than the tops of the units and connected to them by U-bends that can be used as individual water seals. In normal operation, the liquid removed from the gas will discharge on the downstream face of the filter candle and drain away. If there is any channelling, the entrained mist which has not been removed will show clearly on the Perspex roof of the unit. When this occurs, the unit concerned will be isolated by flooding with water. Then it will be safe to remove the roof and withdraw the candles for inspection.



Cutaway diagram of fibre filter unit (Mancuna Eng. Ltd.)

For an acid mist where 100% of the particles are below two microns it is possible to pass 208 cfm through each candle of six elements with a 10-in. w.g. pressure drop. This will reduce an inlet concentration of 0.1 g. H_2SO_4/m^3 to 0.0005-0.0007g. H_2SO_4/m^3.

In addition to its use in sulphuric acid manufacture, other possible applications are for the final discharge gases in the recovery of bromine from sea-water, or the removal of pickling tank mists. There is no reason, however, why it should not be used elsewhere, provided that the fibres are either directly resistant or coated with a layer which is both chemically resistant and hydrophobic. Furthermore, irrigation by diluting the deposited liquid will extend the present range of applications of the fibres.

The process is claimed to be an alternative to electrostatic precipitators or ceramic filters for these duties, but we understand that information is shortly to be released from other sources on operational experience with ceramic filters for removal of such mists from the exit gases of a sulphuric acid producing plant.

* *Trans. Inst. Chem. Eng.*, 1958, **36**, No. 6, 476.

66.045:1:661.66

Fig. 1. Polybloc assembly showing part of the shell and blocks cut away. (Model GM8.)

CONSIDERATIONS ON THE DESIGN OF GRAPHITE HEAT EXCHANGERS

by A. HILLIARD

This paper* discusses some of the considerations which led to the design of a new type of graphite heat exchanger. It shows that when a new material is used for an existing application, it may be preferable to base the design on the properties of the material alone, without reference to existing constructions or prior art. A heat exchanger which was developed on these principles, the Polybloc, is described, and its various features are discussed. The conclusions may be of general interest when considering new materials for existing applications, and they may apply equally to constructional fields outside that of heat-exchanger design.

MOST of the properties which qualify graphite as a constructional material for heat exchangers, particularly for the treatment of corrosive fluids, are well known. They have been discussed in numerous publications and have also been summarised recently.[1] The description of graphite is therefore substantially limited in this paper to some of the less generally appreciated properties of the material.

It is well known that one of the most remarkable features of graphite is its outstanding combination of excellent thermal conductivity with highly versatile resistance to chemical attack.

The main object of this paper is to outline the considerations which led to the adaptation of certain principles of design for graphite heat exchangers, and to indicate how these affected the characteristics of the resulting unit. The term "heat exchanger" is used in its wider sense, and includes industrial equipment for the heating, cooling, evaporation, concentration, distillation, condensation, absorption and stripping of fluids in heat-exchange relationships.

Design Considerations

The first graphite heat exchangers were manufactured in the U.S.A. about 25 years ago[2] to meet an increased call from the chemical industry for equipment resistant to highly corrosive fluids. At that time almost all other heat exchangers were made from metal and were based on the tubular system. This system had been found suitable because most metals are malleable, ductile and substantially isotropic. Moreover, for many metals, there is no serious difference between the tensile and compressive strength.

Probably because most existing heat exchangers were then of the tubular type, the first graphite heat exchangers followed this design. However, the tubular system is not necessarily advantageous in the case of graphite. In contrast to the many metals which are isotropic in most respects, a crystal of graphite is highly anisotropic, and has a thermal conductivity in the direction of the long axes, which is very much higher than that in directions at right angles thereto.[3, 4, 5, 6, 7, 8]

Graphite tubes are made by extrusion, and any preferred crystal orientation is therefore with the long axes parallel to the bore of the tube. Such orientation increases the thermal conduction longitudinally and diminishes it radially, the latter being the direction of required heat transfer.

Mechanically, graphite has one most useful property, namely its good compressive strength. The tensile and flexural strength of graphite are not good. It is therefore undesirable to use graphite in the form of long thin tubes assembled in bundles and subject them to tensile and flexural stresses. Graphite heat exchangers of this kind are mechanically weaker than their metal counterparts.

Cemented joints are usually needed for the assembly of the graphite tubes in the header plates, and floating headers are required to allow for differential expansion. However, it is preferable to avoid cemented joints in graphite constructions for reasons which will be discussed later.

It is a remarkable tribute to the other advantages of graphite that, in spite of these features, graphite tubular heat exchangers were used for many years and in great numbers all over the world. Their use, however, was generally limited to applications where no other convenient constructional material was compatible with the fluids to be treated. It was not general practice, therefore, to use graphite tubular heat exchangers where, for example, a metal unit was chemically satisfactory. It became evident that, if the use of graphite heat exchangers was to be extended, it would be necessary to develop a more robust unit which avoided tensile and flexural stresses and was subjected only to compressive stresses.[9]

Metal-block heat exchangers which satisfied these mechanical requirements had been patented earlier by STANCLIFFE in 1922[10] and 1926.[11] The first suggestion of combining such a metal-block system with carbon was made in a patent by Ruhrchemie A.G.[12] in 1931.

The STANCLIFFE block heat exchanger,[10, 11] being specifically designed for metal, relied for its manufacture largely on the castability of the material. Graphite cannot be cast or sweated, and the method of direct drilling is not practicable for the accommodation in a "continuous" single block of heat-exchange areas exceeding a fairly small limit. The usual practice is, therefore, to assemble

Mr. Hilliard *is technical adviser to the Société Le Carbone-Lorraine.*

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such blocks by cementing together graphite plates, provided on both sides with suitable grooves, and so form the two sets of heat-exchange passages through the block.

Whereas such graphite blocks are much more robust and compact then tube bundles, they involve a multiplicity of cemented joints, and their shape is unsuitable for the use of "circular" header gaskets. Any preferred orientation of the long (conducting) graphite crystal axes is again parallel to the bore of both sets of heat-exchange passages, although this is, of course, less serious in the case of pressed plates than for extruded tubes.[1]

In view of these considerations, it was thought desirable to design a unit around the properties of graphite only, without any reference to prior art. The following principal factors were thought to bear upon the design of such a "new" unit:

(a) the use of compact blocks only, and the avoidance of any long narrow shapes, such as tubes;
(b) the avoidance of any cemented joints;
(c) the maintenance of the unit exclusively under compression and the avoidance of tensile stresses;
(d) any preferred orientation of graphite to be such that the long (conducting) crystal axes connect the two sets of heat-exchange passages;
(e) the use of gaskets of circular shape only; and
(f) the preference for equipment which can be built up from detachable standard unit elements.

It is interesting that the system which satisfied all these requirements was eventually found as the result of an investigation which was not directly concerned with design, but rather with the theoretical aspect of film effect.

Heat-transfer Efficiency

The efficiency of heat exchange is mainly determined by the film coefficients. For a given system the latter are functions of the viscosity, the thermal conductivity, the specific heat and the film thickness. Their effect upon the overall heat-exchange coefficient is often greater than that of the thermal conductivity of the constructional material.

In view of the excellent thermal conductivity of suitably orientated graphite, it was thought interesting to examine ways of encouraging turbulent flow to improve the rate of heat transfer. One way was, of course, to pump the fluids at high speed through the heat-exchange passages. However, such fast pumping is usually neither convenient nor economical, particularly in the case of corrosive fluids. Other methods which were considered are outlined in a previous publication.[1]

One of these, the "end-effect", that is the fact that, as a result of turbulence at the ends of a passage, a film of high resistance to the transfer of heat is not formed immediately at either end of the passage, was considered particularly interesting. The end-effect is a function of the ratio of the length of a passage to its diameter. In the first place it was necessary to determine experimentally under what conditions the end-effect would become significant with respect to heat-transfer coefficients.

A series of tests was made with passages of constant diameter and varying length, and overall heat-exchange coefficients were measured under otherwise identical conditions. For example, it was found that with water flowing at a speed of 31 cm/sec., the improvement in heat-exchange coefficient became significant when the ratio of the length to the diameter of the passage is reduced to 15:1, and it is important for a ratio of 11:1 or less. It is hoped to publish at some future date a description of this series of experiments and to deal also with the theoretical aspect. Here the much more important practical developments which followed are described.

The aforesaid results would have remained of no more than theoretical interest unless they could be utilised in a

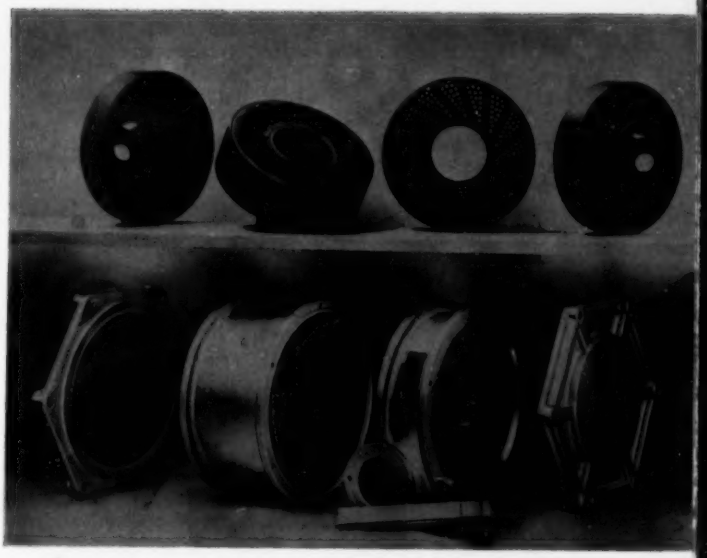

Fig. 2. Graphite heat-exchange elements and header blocks; and metal shell elements of Model GM8.

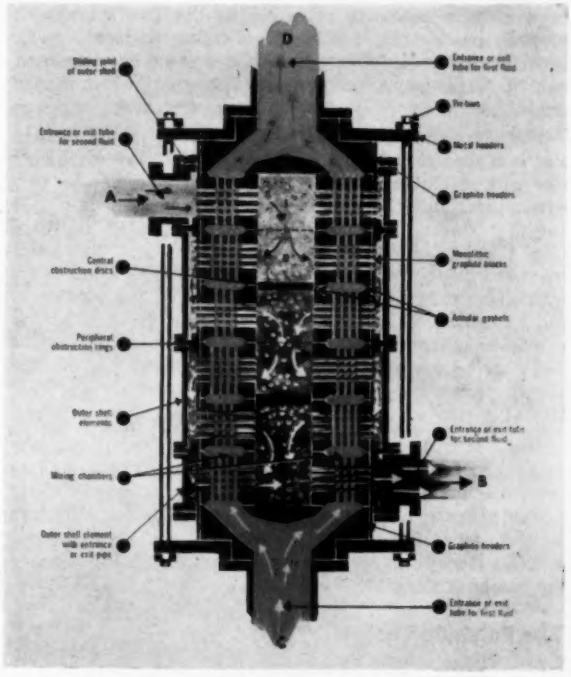

Fig. 3. Diagram showing the flow paths through a Polybloc heat exchanger.

Fig. 4. Polybloc graphite blocks of Super Model SM18, Standard Model GM8 and Small Model PM.

heat-exchanger design which satisfied the constructional conditions (robustness, versatility, freedom from cement joints, etc.) outlined earlier. As it happened, they not only fitted in with these conditions, but the Polybloc heat-exchanger design, as described hereafter, was evolved as the direct result of attempts to incorporate passages of small length/diameter ratio into a block system.

Polybloc Heat Exchanger [13, 14, 15, 16, 17, 18]

The basic element of Polybloc constructions is a cylindrical graphite heat-exchange block as, for example, that shown in Fig. 2. It is provided with a central axial hole and two sets of heat-exchange passages. One set, the axial passages, runs parallel to the axis of the block. The second set, called "radial" passages, is interspaced between the axial passages, and connects the central hole of the block with the outer periphery. They may be either precisely radial or may deviate somewhat. The provision of the central hole makes it possible to accommodate much larger heat-exchange areas in a block without cemented joints than would be practicable otherwise.

Grooves for outer and inner peripheral gaskets are provided around the sets of axial passages at each end of the block. The space between the gaskets may be slightly grooved to provide turbulence chambers, and staggering of the passages will then prevent the carrying over of the heat-transfer-inhibiting fluid film. The blocks are assembled in a column and are provided at the two ends with graphite header blocks acting as distributors (see Fig. 2). Inner and outer peripheral gaskets are placed between each pair of blocks to prevent contact of the two heat-exchange fluids.

The outer shell is assembled from strong metal sections and is placed round the column of graphite heat-exchange elements. Metal header plates are provided at the two extremities, and the column and the assembly are held together under compression by spring-loaded tie bars (Fig. 1), or by other clamping means. The outer shell bears upon the column of graphite blocks by sliding joints only, thus eliminating any risk of stresses arising from differential expansion. Elasticity of the system is ensured by the provision of springs at the ends of the clamping devices (e.g., spring washers under the tie bar nuts) and by the elastic gaskets between the blocks. The assembly and flow characteristics are indicated in Figs. 1 and 3 respectively.

Figs. 1 and 3 are merely intended to indicate the principle of construction. By introducing minor modifications a large number of variations of the arrangement are possible. Practically all process requirements can therefore be met under the conditions which are the most favourable for the given application. This versatility is one of the major features of the design.

The Polybloc Design

Construction from Standard Units

Each exchanger is assembled from fully standardised unit elements which permit the building up of varying heat-transfer areas in a single apparatus simply by adding the requisite number of unit sections. In the model shown in Fig. 2 each section comprises two graphite blocks and one shell element; each block being identical with and fully interchangeable with any other block in the unit. This permits great versatility and important economies if, for example, it is desired to extend production for a given process. Such increase in the size of the exchanger can easily be carried out on the user's site after installation. It also permits the use of the same basic unit for a process from the pilot-plant stage, through trial production, to full industrial manufacture, simply by increasing the size at each stage by the addition of the requisite standard units.

Polybloc arrangements are at present made in three standard sizes, as shown in Fig. 4.

Small Model: which has a minimum heat-exchange area of 0.1 m.^{2} and can be increased in multiples of 0.1 m.^{2} to a maximum of 3 m.^{2}.

Standard Model: with a minimum area of 1 m.^{2} which can be increased in multiples of 1 m.^{2} up to a maximum area of 11 m.^{2}.

Super Model: which has a minimum area of 3½ m.^{2} and can be increased in multiples of 3½ m.^{2} up to a maximum of 56 m.^{2} heat-exchange area in one single unit.

Basic blocks are available with passage sections of varying diameter and, if required, of varying contours. Passages are usually parallel-sided, but in some cases, e.g., if used for absorbers, they are trumpet shaped.[18]

Versatility of Arrangement

With the aforesaid small number of basic standard unit elements, it is possible to produce a very large number of different arrangements, and to meet any given process requirements to the best advantage. For example, the passage diameter and contour can be selected to suit best the requirements of the medium to be treated. The passages can be either staggered or aligned, thus permitting the control of the degree of turbulence at which the fluids flow through the unit. If liquids are to be treated, it is generally desirable to inhibit streamline flow, and, in this case, the passages are staggered as shown in Figs. 2 and 3. The turbulence effect is, therefore, regenerated many times during the fluid passage through the heat exchanger, which results in remarkably high coefficients of heat exchange. On the other hand, if an evaporative process is involved, it may be preferred to align the passages and also to select passages of a larger diameter. The most convenient area of flow can be selected from a number of different flow-sections within the range of 25 cm^2 to 640 cm^2.

Polybloc arrangements are thus suitable for a multiplicity of duties including industrial heating, cooling, evaporation, concentration, distillation, condensation, absorption and stripping. Moreover, they are especially suitable when resistance to corrosive fluids is necessary.

Robustness

The robustness of the graphite blocks can be observed from the illustrations of Figs. 2 and 4. It will be seen from Fig. 1 that the graphite parts are held together under compression only, so that tensile stresses are avoided. Full advantage is taken of the good compressive strength of graphite. The assembly is protected against external impact by the strong metal shell which completely envelops the column of graphite blocks and by the thick metal header plates at the two ends of the column. Consequently, the robustness of the assembled unit compares with that of metal constructions, and this is probably one of the reasons why the Polybloc has found such wide application in the heavy industries. It will also be noted that the compact units accommodate a considerable heat-exchange area in a comparatively small volume. Thus, in the case of a SM10 model of 14 blocks, the heat-exchange area for each fluid is 49 m.^{2}. The height of such an assembly is a little under 3¼ m. and the extreme diameter is 80 cm.

Corrosion Resistance

The process liquor contacts only highly inert, impermeable monolithic graphite blocks and gaskets of comparable chemical resistance. Industrial applications where heat exchange between two corrosive fluids are involved are not frequent. However, when this is the case, it is easy to provide the outer shell with a suitable corrosion-resistant lining. The remarkable chemical resistance of graphite to

corrosion has been discussed on many previous occasions, and it is well known that graphite is inert under the conditions of most industrial applications.

Resistance to Erosion

Although graphite is generally softer than metals, its resistance to erosion by liquids and gases is often better than that of many constructional metals. For example, it may be found that a graphite plate subjected to a continuous steam jet may be substantially unaffected, while a steel or other metal plate may, under similar conditions, be worn away within a comparatively short period. A reason for this remarkable erosion resistance of graphite is its chemical inertness.

Returning to the example of erosion by steam jet, the mechanism in the case of metals and other reactive materials is usually as follows. A surface film may be formed on the metal as the result of chemical reaction between the impinging steam (or other) jet and the metal. Because of differential expansion, or for other reasons, this layer of reaction product may then be loosened and swept away by the impinging jet, exposing the clean metal face beneath to new chemical attack. If this process is continued progressively, it may eventually result in the wearing away of the metal surface. Because of its versatile chemical inertness, graphite is not usually susceptible to this mechanism of attack. The remarkable erosion resistance of graphite in the absence of solid hard particles in the impinging fluid is, therefore, largely due to the freedom of the material from chemical attack. It is, of course, a question of definition whether this aspect of graphite should be discussed under the heading of "erosion" or "corrosion".

Freedom from Cemented Joints

The fact that there are no cemented joints in any part of the Polybloc construction is of great practical importance. Cements which can be used in connection with graphite are generally based on a suitable resin. The resins are more sensitive than graphite to thermal changes and chemical influences. For instance, many of the fluids which are treated in graphite heat exchangers may induce continued polymerisation of the cement resins. This, and other forms of chemical or thermal attack, may culminate in the deterioration or destruction of the joints. It was therefore considered important to avoid any cement joints in the Polybloc, and to exploit as fully as possible the thermal and chemical stability of graphite.

It should be explained here that most graphites used for heat exchangers are impregnated to plug up residual permeability, and that the impregnants used may be resin-based. The question may be asked why it is important to avoid cemented joints if resinous impregnants are used in the pores of the graphite? The main reason is that, as an impregnant in the very fine pores, the resin is shielded by the mass of graphite round it and has no other mechanical duty than to stay in the pores. As a cement in a joint, the resin has the duty of holding together a structure against external mechanical stresses, as well as the even more severe stresses which may result from differential expansion. In addition to chemical inertness and mechanical strength, a cement resin must be adhesive. This limits the range of resins available for cements and may necessitate a compromise with regard to their properties.

The impregnants in graphite, having practically no mechanical duty, may be selected with respect to their chemical inertness alone, which means that they can be chosen from a much wider range of available materials. Impregnants are not limited to resins and, if required, their range may extend to carbonised materials.

Fluid Tightness

Fluid tightness is ensured by suitable gaskets between the blocks. These gaskets replace the cemented joints of other constructions, without being subject to their limitations. Most Polyblocs are provided with PTFE gaskets (Teflon or Fluon) and their chemical resistance is therefore as good as that of the graphite material. A major advantage of the gaskets is that they are interchangeable, and even if synthetic rubber or other inexpensive gaskets are used, they can be easily replaced whenever required. Another advantage of using detachable gaskets is that the whole assembly is fully detachable, giving the constructional and operational benefits already discussed.

In addition to chemical inertness, the gaskets must, of course, be fluid tight. In this respect their shape is of primary importance. It is well known that the easiest gaskets to make fluid tight are those of circular shape. This is the reason why the Polybloc elements are cylindrical, and Polybloc assemblies remain fluid tight even under highly strenuous operational conditions.

Thermal Conductivity

Reference has already been made to the effect of orientation of anisotropic graphite crystals on thermal conductivity. Since the heat-exchange passages through the Polybloc are made by drilling, it is arranged that the preferred direction of the long (conducting) axes of the graphite crystals joins the two sets of heat-exchange passages. This is possible because the directional arrangement of passages can be freely selected in the case of homogeneous monolithic blocks. Accordingly, it will be seen from Figs. 2 and 4 that the two sets of heat-exchange passages are so arranged to achieve the preferred anisotropic orientation of graphite crystals for best conditions for thermal conductivity.

Heat-exchange Efficiency

The Polybloc takes advantage of the end-effect for improved heat-exchange efficiency. As already explained, all heat-exchange passages in the blocks are very short with respect to their diameter. This causes turbulence in the fluids at comparatively slow rates of flow. The thermal effect of this is illustrated by the overall heat-exchange coefficient graphs as given in Figs. 5 and 6. Fig. 6 refers to steam/water coefficients with the Standard Model (GM8). It will be noted from Fig. 5 that the coefficients obtained with the Small Model (PM) under comparable conditions are even better. This is because one set of heat-exchange passages in the Small Model is of smaller length/diameter passage ratio than the corresponding passages in the Standard Model. This improvement of heat-exchange coefficients as a function of decreasing length/diameter passage ratio is in line with a number of experimental results which were obtained in the course of the examination of this question.[1]

Anti-fouling Effect

Fouling, namely the deposit of scale on the heat-exchange passages, can have a serious effect upon the operational efficiency of a heat exchanger. Fouling scale can be classified into two groups.

(1) Scale formed on the heat-exchange passages as the result of chemical reaction between the material of construction and the process liquor. This type of scale is usually found with metal units as many metals react with a wide range of fluids, thus producing solid compounds, usually in the form of scale on the heat-exchange walls. The scale acts as a thermal insulator, or it may peel from the metal and erosion is produced. Scale which is the result of chemical attack by the process liquor on the constructional material does not occur in the case of graphite, because graphite forms no solid compounds.

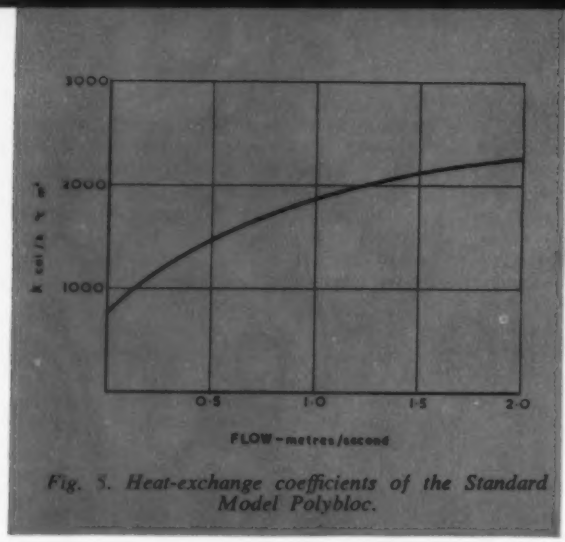

Fig. 5. Heat-exchange coefficients of the Standard Model Polybloc.

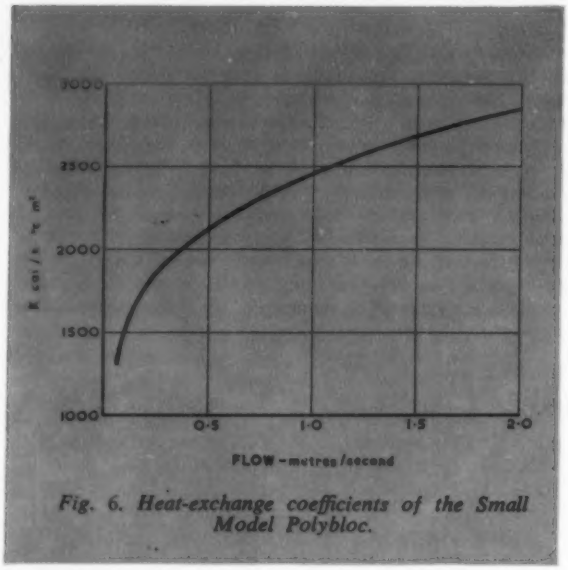

Fig. 6. Heat-exchange coefficients of the Small Model Polybloc.

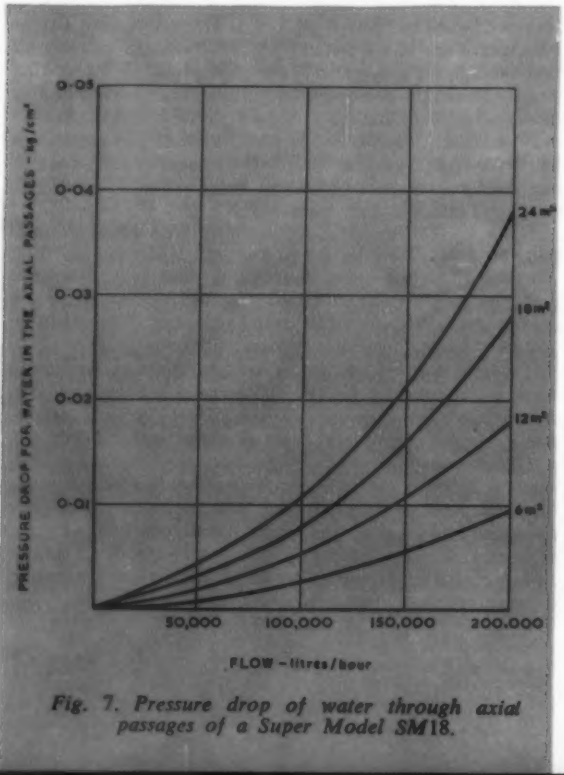

Fig. 7. Pressure drop of water through axial passages of a Super Model SM18.

(2) The second kind of scale, held on the heat-exchange passages by surface forces, may be formed even in the case of substantially inert materials, like graphite. If a solid phase is produced in a heat-exchange fluid, either by precipitation or otherwise, solid particles may tend to build-up on the walls of the heat-exchange passages and such deposits have a serious heat-transfer-inhibiting effect. If their build-up is allowed to continue, the pressure drop will increase owing to the decrease in the area of free flow. The best example is perhaps the deposition of iron sulphate in the passages of heat exchangers which are used for the heating of steel pickling liquor. This requires not only larger heat exchangers than would be required if the passages remained clean, but it also involves frequent cleaning, which is troublesome, costly and interrupts production.

The cleaning operation is less cumbersome in the case of graphite than with more reactive materials of construction, because suitable solvents can be passed through the graphite passages. This method of chemical cleaning is generally less costly and troublesome than is mechanical cleaning. Nevertheless, it is preferable to avoid the formation of scale in the first place. The anti-fouling effect of the Polybloc is therefore of particular interest.

The development of scale deposits which are not the product of reaction between constructional material and process fluid is favoured by stagnant conditions; as, for example, the stagnant layer of fluid associated with laminar flow. The turbulent flow which is encouraged by the small length : diameter ratio of the Polybloc passages and by the multiplicity of turbulence chambers between the blocks has, therefore, a pronounced scale-inhibiting effect. More details about this aspect of the equipment are in process of being published in a separate paper.[19] A plant for heating steel-pickling liquor is discussed. In this plant, Polyblocs, after a year of continuous operation, are still performing at the initial, overall heat-exchange coefficients of approximately 1950 Kcal./hr °C m.², without ever having been cleaned. The heating units previously employed had to be descaled about every ten weeks.

It is also recalled that the steam-water heat-exchange coefficients shown in Fig. 6 were obtained with a Polybloc which had been used for a considerable period for the continuous heating of steel-pickling liquor.

To take advantage of the scale-inhibiting effect of the Polybloc, it is advisable to observe certain elementary operational precautions, particularly when the plant is shut down. For example, care should be taken to continue circulation of the cooler fluid for a few minutes after shutting off the hotter fluid. Thereafter, all liquid should be drained from the Polybloc.

Pressure Drop

Control of pressure drop over a wide range is practicable by judicious selection of passage diameter and flow sections, and by the degree of staggering of the passages. This permits a wide range of adjustment to suit particular conditions.

The remarkably high heat-exchange coefficients obtainable with the Polybloc decrease correspondingly the required heat-exchange area, and this also reduces the pressure drop accordingly. Figs. 8 and 9 illustrate the pressure drop of air and water respectively through the axial passages of the Standard Model with passages of 8 mm diameter. In the case of the Standard Model with passages of 16 mm diameter, the axial pressure drop is only one-fifth that shown in the graphs of Figs. 8 and 9. Fig. 7 shows the pressure drop for the Super Model with axial passages of 18 mm diameter. The pressure drop is, in turn, only a small fraction of that for the Standard Model. When interpreting the pressure drop figures, it is

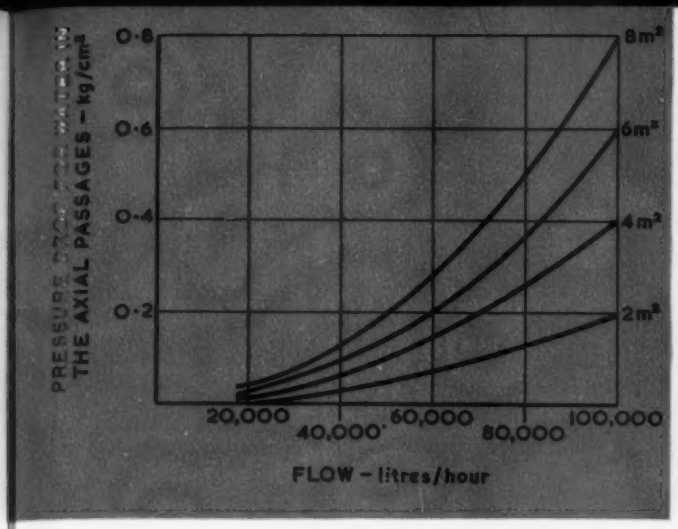

Fig. 8. Water through axial passages.

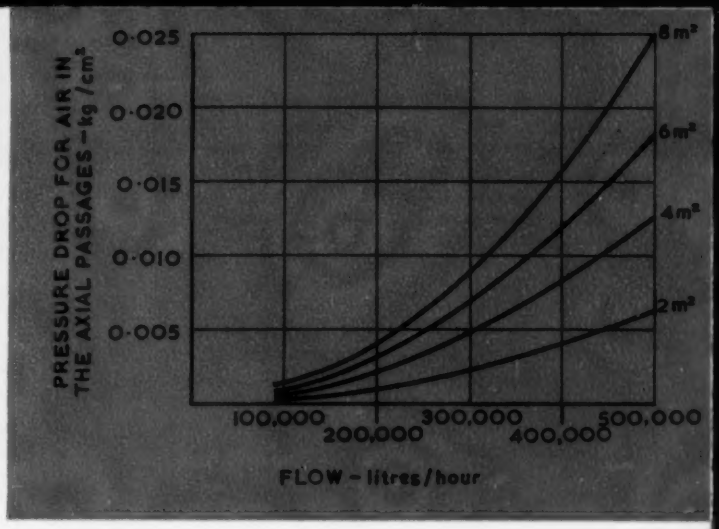

Fig. 9. Air through axial passages.

necessary to consider them always in conjunction with the heat-exchange coefficients; it will then be seen that the pressure drop aspect is remarkably favourable.

SIMPLICITY

It is an advantage for industrial equipment to be as simple as possible, a condition which is amply fulfilled by the Polybloc design. A very large number of variations of construction are possible from a comparatively small number of standard unit elements. This is not only of benefit to the user, but also of considerable importance for the manufacture of the equipment, since it permits mass production. Moreover, because components of the design are standardised, they can be easily interchanged on site. However, this has proved of less practical importance than was originally thought, because the units are so robust that they rarely require attention.

Conclusions

It will have been seen that the constructional principles upon which the Polybloc is based differ considerably from those of the more conventional heat exchangers. As was explained in the introductory section, this is because it was considered necessary to design the unit in direct relation to the properties of graphite, without reference to prior art. From the very successful performance large numbers of Polyblocs are giving in a wide variety of industries throughout the world, it would appear that this decision was correct.

ACKNOWLEDGMENTS

The author wishes to express his particular appreciation to MR. J. CLAUSE, the technical director of Société Le Carbone-Lorraine, for his invaluable guidance and for his solution of the many problems which beset the road to success. It was thanks to the conspicuously successful solving of the practical problems by MR. CLAUSE that the developments were brought to the stage of industrial usefulness.

REFERENCES

[1] Hilliard. "Some Recent Developments in Graphite Heat Exchangers and Similar Equipment", Carbon & Graphite Conference, Society of Chemical Industry, London, September, 1957.
[2] Mantell. "Industrial Carbon", 1956 (New York: Van Nostrand).
[3] "Contribution à l'étude de certaines propriétés des charbons et graphites industriels", Albert, June 1955. Internal publication, Société Le Carbone-Lorraine.
[4] Goetz and Holser. *Trans. Electrochem. Soc.*, 1942, **82**, 391.
[5] Krishnan and Ganguli. *Nature*, 1939, **144**, 667.
[6] Dutta. *Phys. Rev.*, 1953, **90**, 187.
[7] Tyler and Wilson. *Phys. Rev.*, 1953, **89**.
[8] Brown, Watt, Powell and Tye. *Brit. J. App. Phys.*, 1956, **7**.
[9] "Delanium Carbon in Chemical Plant Construction". Norman, Hilliard and Sawyer. Conference on Materials of Construction in the Chemical Industry, Birmingham University, April, 1950.
[10] Stancliffe. U.S.P. 1,571,068 of January 26, 1926 (Appn. August 7, 1922).
[11] Stancliffe. B.P. 285,151 (Appn. November 11, 1926).
[12] Ruhrchemie A.G. B.P. 391,817, September, 1931.
[*13] Le Carbone-Lorraine and Hilliard. B.P. 756,327.
[*14] Le Carbone-Lorraine and Hilliard. B.P. 756,420.
[*15] Le Carbone-Lorraine, Clause, Hilliard *et al.* B.P. 736,305.
[*16] Le Carbone-Lorraine, Clause and Hilliard. B.P. 739,906.
[*17] Le Carbone-Lorraine and Hilliard. B.P. 797,544.
[*18] Le Carbone-Lorraine and Hilliard. B.P. 808,728.
[19] "Savings with New Type Graphite Heat Exchanger in Steel Pickling Plant", by Garman, Hilliard and Riches (to be published).
* *Note:* For brevity, the literature references 13, 14, 15, 16, 17 and 18 cite only the British numbers of the respective Polybloc Patents. It should be noted that corresponding Convention Patents have been granted in other countries where such Patents were applied for. All these Patents cover the constructional features generally and are not limited to any specific material.

The Key Service

REPORTED as the "key to the world's chemical literature", the chemical abstract service of the American Chemical Society was again in the news with the appointment of D. B. Baker as its director and Dr. C. L. Bernier as editor of the Society's 52-year-old publication, *Chemical Abstracts*. This publication is a semi-monthly containing brief summaries of articles on chemical subjects from more than 8000 scientific, technical and trade periodicals representing 85 countries and appearing in more than 40 languages. Material is also gathered from patent specifications used in 22 countries and from books and other publications containing new chemical information. Altogether, more than 115,000 summaries are prepared each year by some 2000 experts in various branches of chemical science and technology.

Mr. Baker, the new director of the abstracting service, commenting on his appointment, stated that he will seek continually to expand the information services to keep pace with the rapid activity of the world's chemical engineers and chemists. Besides participating actively in affairs of the American Chemical Society, Mr. Baker is vice-president of the National Federation of Science Abstracting and Indexing Services and a member of the American Association for the Advancement of Science, while his colleague, Dr. Bernier, has published numerous papers on fundamental research in the theory of indexing and on other aspects of abstracting and indexing problems.

Besides the publication of *Chemical Abstracts*—itself a service—the publications staff prepares an annual index and collective indexes covering authors, patents, subjects and formulæ. The "Fifth Decennial Index", now in preparation, will run to 19 thick volumes containing some 22,500 pages of fine-print indexes. The service also maintains a research department to study new systems for recording and retrieving scientific information, and issues several other publications on such subjects as the naming and indexing of chemical compounds and the standardisation of chemical nomenclature. The service is believed to be the world's largest single source of nomenclature information.

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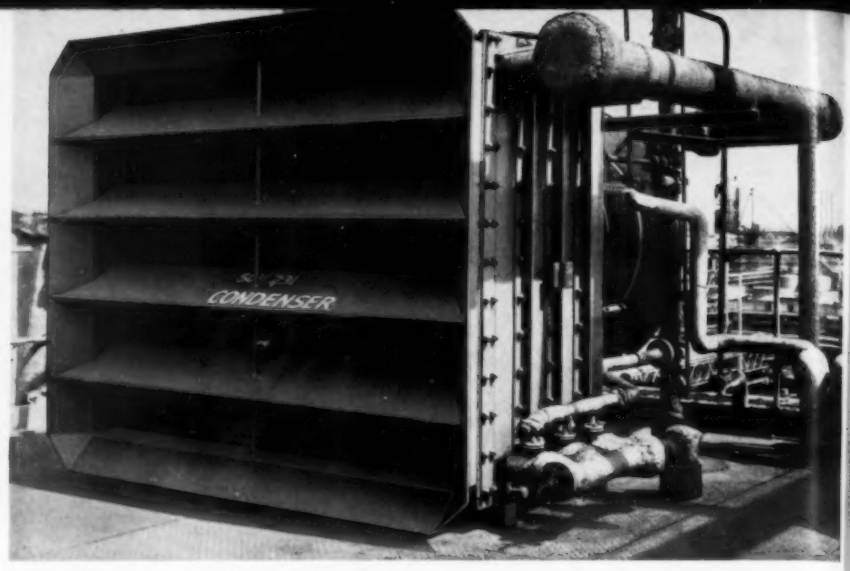

Fig. 1. An air-cooled chemical plant condenser situated some 150 ft above ground level. (Photo: Wellington Tube Works.)

ECONOMIC CONSIDERATION OF AIR-COOLED HEAT EXCHANGERS

by GODFREY WINTERS, B.Sc. Tech., M.I.Chem.E., A.R.I.C.

An account of the most important points to look for in selecting an economic design

STATIC plant has usually been water-cooled, a practice demanding a plentiful supply of cooling water at the plant site. Air cooling has been restricted to mobile equipment or waterless sites. Recently, however, as a result of numerous studies on air- and water-cooled equipment installation and maintenance costs, it has become apparent that air can be economically used as a coolant over a much wider field than was previously thought possible. Moreover the attractiveness of air cooling has been enhanced by the general shortage of good cooling-water supplies. It is important, therefore, to be able to make realistic comparisons between air-cooled equipment and the water-cooled, shell-and-tube type of exchangers which they may replace. Invariably it is necessary to base comparisons upon individual designs.

General Considerations

Sometimes the technical advantages of air cooling override economic considerations (as is discussed later), but in most cases careful comparison of the alternatives is necessary and then the cost of items shown in Table I ought to be considered.

New Plants

The first cost of an air-cooled heat exchanger will usually be greater than its water-cooled counterpart; often it will be two or three times greater. Nevertheless, when *all* costs are taken into account, about two-thirds of large cooling installations will be more economic using air cooling.

Since both running and capital costs have to be considered, the higher capital cost of the air-cooled exchanger would not usually favour its selection where the plant amortisation period is short. Hence, large long-term projects offer a better field for air cooling than do small, short-term ones.

Existing Plants

In the case of old installations which are due to be extended or re-equipped, it is more difficult to make a case for air cooling. The investment represented by various items in Table I may already either be written off partially or completely. Alterations to existing pipelines may be required where air-cooled equipment is to be installed, its greater size might well prove embarrassing, and the increased electrical demand might overload facilities otherwise adequate. In circumstances such as these at existing plants air cooling is seldom preferred to water cooling.

Despite this, however, even though a preliminary view may discourage the use of air cooling for any one duty, a more careful survey may show that the process as a whole will benefit from its use. Air cooling can, for example, be introduced into a general water-cooling system; thus the substitution of air coolers at high positions in a plant can, by reducing the head required for the complete water supply, achieve considerable economies. Booster pumps can also serve this purpose, but not as well.

Other unique advantages of air-cooled exchangers which may override economic considerations are:

(a) product free from contamination by water;
(b) elimination of plant shutdowns in frosty weather;
(c) combination of heat-transfer duty with a ventilation requirement.

Influence of Alternative Water Source

The case for or against air cooling, whether for new or old installations, is influenced also by the source of the cooling water available for water-cooled equipment, since the temperature, corrosive nature and cost of any cooling water supply have all to be considered.

Mr. Winters *is Projects Manager, Heat Exchange Division, Wellington Tube Works Ltd.*

(a) Water from a Cooling Tower

Water from a cooling tower is probably the most commonly used coolant in large installations. It is often thought that air coolers suffer a major handicap, when compared with water coolers, since air is warmer and the consequent temperature differences are lower. In this country, however, this view is mistaken if cooling-tower water is considered. Cooling towers are usually designed to produce cooled water at a few degrees above a maximum (or optimum) summer, ambient, wet-bulb temperature. Humidities in Britain are usually high, and the resultant cooled-water temperature is thus always about the same level as the maximum (or optimum) summer, ambient, dry-bulb temperature. This latter figure is itself the ambient temperature used in air-cooler design, and hence the initial design point is almost the same in both cases. To illustrate this point, suppose the basic ambient temperature for air-cooled design is 75°F (dry bulb). If the average relative humidity is 60%, the corresponding wet-bulb temperature is 65°F, and a cooling tower would be designed to provide cooling-tower water at, say, 73/77°F. Both air- and water-cooled equipment, therefore, start from very much the same temperature level. Thus, in Britain, air coolers have a real basis for competing with water-cooled equipment used in conjunction with cooling-tower water.

The above figures also indicate why the use of evaporative coolers in Britain should be avoided, since in almost every case the disadvantages of introducing water outweigh any slight advantage in temperature thereby gained. Engineers in temperate climates should not be misled by the information on evaporative cooling based on experience, particularly in Texas and the Middle East where the climate is notably hotter and drier. The only exception might be made where a product-outlet temperature around or lower than the ambient dry-bulb temperature is really necessary. Even so, a dry air cooler followed by a conventional water-cooled exchanger (if the water available is cold enough) will often give better economy, and so will a relaxation of the outlet temperature requirement for an insignificant portion of the year.

Table I

	Water Cooling	*Air Cooling*
A. Capital Costs	1. Heat exchanger	1. Heat exchanger
	2. Process fluid pipeline	2. Process fluid pipeline
	3. Exchanger site	3. Exchanger site
	4. Exchanger foundations	4. Exchanger foundations
	5. Cooling tower (or part of)	
	(a) Foundation and basin	
	(b) Ground area	
	(c) Power Installation (Fans)	5. Power installation (fans)
	6. Water circulation system	
	(a) Pipelines and valves	
	(b) Pumps	
	(c) Ground area	
	(d) Power installation (pumps)	
	(e) Water treatment plant	
B. Running Costs	7. Maintenance of exchanger (process side)	6. Maintenance of exchanger (process side)
	8. Maintenance of exchanger (water side)	7. Maintenance of exchanger (air side)
	9. Maintenance of cooling tower	
	10. Water treatment	
	11. Water make-up	
	12. Pumping power	
	13. Fan power (cooling tower)	8. Fan power

(b) Water from other Sources

Sea, estuarine, or other surface waters will have a temperature advantage over air since their temperatures are often very close to the air wet-bulb value and might even be a little lower. The effect of this lower temperature will be most marked when low outlet-product temperatures are required; hence, though condensers may be economically suited to air as the coolant, it is likely that for coolers water will be the more favoured. But beware of estuarine and river waters which, through discharge of industrial effluent, may have temperatures even higher than the dry-bulb temperature.

Against the temperature advantage of water, however, must be set the fact that exchangers using sea or estuarine water always present corrosion problems. Usually they require for their construction such materials as brass, cupro-nickel, etc., rather than steel, which might be very suitable for the air-cooled design. These remarks do not invalidate the statement above on condensers and coolers. Nevertheless, it is possible to find situations where an excellent case can be made for the use of air as a coolant, including some requiring "close approach" coolers.

Where towns water is a possible coolant, its lower temperature and the freedom from severe corrosion would seem to make the case for air cooling difficult. So high is the cost of towns water, however, that air is the more economic alternative without exception.

Borehole and well-waters are usually colder than air, and so also have an apparent advantage, but before they can be successfully used they generally have to undergo water treatment. This may well reduce or nullify any advantage they possess.

Clearly, the cheaper, purer and colder the water supply, the less favourable becomes the case for air cooling. Good water, however, is seldom cheap and the available supplies are frequently very limited. Air is free from this disadvantage, since it is present in unlimited supply, and the quantities which can be used are governed solely by economical considerations.

Cost Factors and General Design

In every case so far mentioned it has been assumed that the economic "optimum" exchanger has been under consideration whether air- or water-cooled. With water-cooled exchangers, "optimum" design conditions and exchanger types and costs are well established and a good plant designer should not stray too widely from the best combination of economy and operational suitability. With air-cooled exchangers, however, design conditions, types and cost factors are nothing like so widely known and gross errors are much more easily made. In contrast with water-cooled systems, the "optimum" condition with air-cooled systems is much more critical. It is thus difficult, or even impossible, for the ordinary plant engineer to put forward an adequate case for air cooling unless he has at his disposal specialist advice in this field.

The major reason for this is that the thermal and mechanical design of air-cooled equipment requires not only a knowledge of extended surface heat exchange and its economics, but also of air movement economics and good fan practice. One can successfully and economically

design a water-cooled exchanger without a knowledge of pump costs and characteristics, but any attempt to design economic air-cooled exchangers without a full knowledge of fan costs and characteristics is likely to fail.

Line (a) of Fig. 2 shows a typical curve of air-cooled heat exchanger capital costs, excluding fan and motor, against varying power installation for a given heat-transfer duty. As might be expected, the capital cost of the exchanger reduces with increase in power, but this simple relationship is misleading; no consideration of air-cooled heat-exchanger costs should exclude the cost of the fan and its motor, even though these latter items may be purchased independently of the heat exchanger itself. When fan and motor costs are added, as shown by line (b) of Fig. 2, the overall capital cost savings with increased power installation are very much diminished and a state of affairs is soon reached where an increase in power causes little or no capital saving. The correct combination of initial capital cost and associated horsepower installed should thus be chosen most carefully.

In the economic assessment it is usual to add a further "capital" cost to that of the exchanger, fan and motor to allow for the wiring, sub-station work, starters, etc., necessary to the installation. The effect of this is shown by line (c) of Fig. 2, which indicates that an increase in power can even cause additional outlay. This shows that, in order to avoid unnecessary power installation, all the more care should be taken to obtain the correct exchanger to horsepower relationship.

It might be concluded that the correct "design" point is the one indicated by the minimum "capital cost" point of line (c), but this is not so. In approaching that position, it must be remembered that the attendant capital savings for similar increases of power diminish gradually. The actual "design" point depends not only on capital costs and on the cost of power installed and consumed, but also on the amortisation period allowed and the required return on capital outlay. For these reasons would-be purchasers of air-cooled heat exchangers should always state the write-off period that the designer can assume. They should also give the cost of power and the number of hours per year the unit will run. Failure to do this will lead to the receipt of a number of non-comparable tenders from which no reliable final selection can be made.

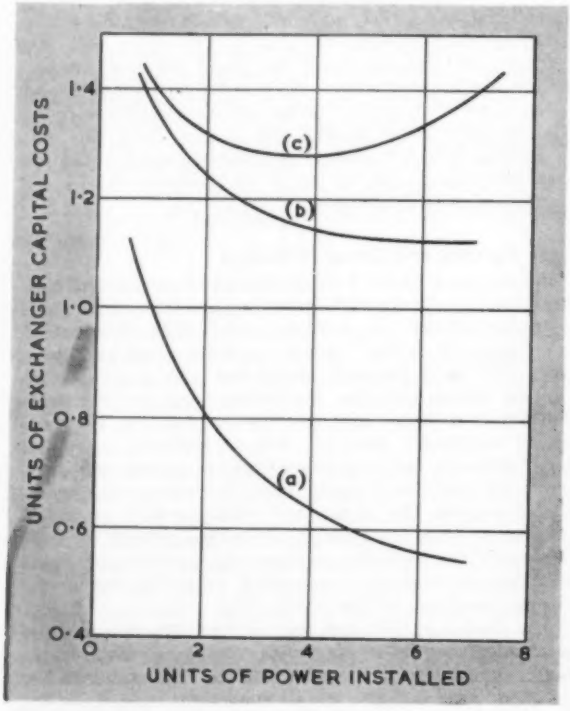

Fig. 2. Effect of power on capital costs.

Fig. 3, which is based on line (c) of Fig. 2, shows the effect of the amortisation period upon the amount of power which would be installed on an economic air-cooled heat exchanger designed for a given heat-transfer duty; also upon the initial costs of the heat exchanger itself complete with fans, structure, etc. Because power consumption becomes more important and initial capital costs less important as the amortisation period lengthens, the amount of power which should be installed varies very sharply, and a long-term amortisation period calls for low power installation and high initial capital costs.

Horsepower Installation

The horsepower which should be selected for any given air-cooled heat exchanger is dependent on a complex function which ideally takes into account the thermal characteristics of the heat-exchange surface to be used; the relationship between ambient temperature and process fluid operating temperatures; the cost of moving a unit weight of air through different pressure levels (capital cost for fan and motor and running cost for power); the cost of a unit area of heat-exchanger surface (including such extras as structural work, header boxes, value of site, etc., as well as the cost of the extended surface tubing); and, of first importance, the internal heat-transfer coefficient which can be obtained with the process fluid. For a given type of heat-exchange surface, high internal heat-transfer coefficients lead to the use of large volumes of relatively high velocity air and of high power to exchanger cost ratios. With low internal coefficients, which probably control the thermal design, lower air-movement rates and smaller power installations are an economic necessity.

Extended Surface Tube Selection

Any type of extended surface tubing intended for use in an industrial air-cooled heat exchanger should satisfy a number of requirements. It should be cheap, robust and reliable, both thermally and mechanically. An efficient and relatively incorrodible carrier for the process fluid must be combined with an external surface capable of dissipating the maximum amount of heat whilst using the minimum amount of power (pressure drop), and presenting the highest resistance to atmospheric corrosion and dirt retention. Theoretically, the ratio of inside to outside surface should exactly suit the thermal design under consideration, fin efficiency should be high, and a maximum amount of surface should be packed into unit volume.

In practice no one type of surface measures up to these requirements infallibly. Manufactureres have their own "standards" which they produce regularly and cheaply, and the advantages to be gained from using them invariably outweigh any of the inherent theoretical disadvantages they might possess. (The development of a special size and type of tube for use in atomic power plants is the only exception to this rule, arising from the unique duty and the quantities involved).

It must be emphasised that in comparing two different types of extended surface, equally suitable for a given duty, cost and area alone are not sufficient criteria. These two factors must be considered along with two others—namely, heat transfer (allowing for surface efficiency) and pressure drop—with the tube packing characteristic exercising an additional but minor influence. The cost per unit area of finned tube if considered alone can be very misleading. What is of prime importance is the quantity of

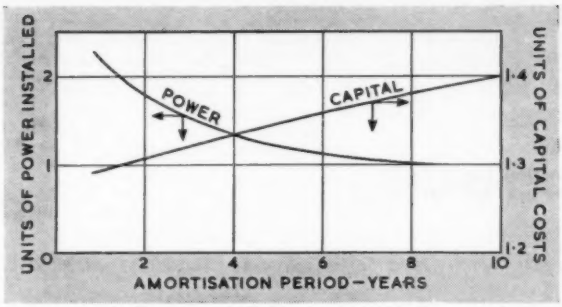

Fig. 3. Effect of amortisation period on power and capital costs.

heat transferable per unit of area and per unit of pressure drop for a given unit of cost.

Power Economy and Process Control

Having taken into account all the factors discussed so far, additional consideration must be given to the possibility of saving fan power at all times when the actual operating conditions are less severe than the design conditions, the most obvious example being power reduction in winter. This is important, because the cost of power used is generally assessed on an annual basis. There are a number of means of saving fan horsepower in order to reduce running costs, and these may be briefly classified into four main groups. In making these classifications, however, it must be remembered that on many occasions control of the process temperature and heat load also involves fan horsepower changes, and these may either govern or be indistinguishable from those changes made for economy reasons alone.

(1) *Variable flow devices for fixed-pitch fans, e.g., louvres, dampers, by-passes, etc.*

Where installed fan power is low and small volumes of air are being moved a method from this group is often preferable, since low first costs are involved and the relative power inefficiency is tolerable.

(2) *Variable-pitch devices for fixed-speed fans*

Until recently, this method, which is most popular in American oil refineries, was considered the ideal answer in almost every case and irrespective of plant location. If, however, an analysis of the possible power saving by this method is made, it will be readily seen that the extremes of temperature needed to make it economic are certainly not to be found in Britain. Because of this, and also due to the prohibitive cost of small variable-pitch fans, this method should rarely be used. Only when exceptionally large units and large variable-pitch fans are under review should it even be considered.

(3) *Variable-speed devices for fixed-pitch fans, e.g., hydraulic drives, variable-speed motors, variable gearboxes*

This method could be said to possess certain technical advantages over the others, but it is doubtful if the costs involved can ever be justified. Additionally, and remembering that ease of maintenance is a prime factor in the selection of air for cooling, the introduction of the complicated mechanical equipment usually required here is to be deprecated.

(4) *Change-speed devices for fixed-pitch fans, e.g., dual-speed motors (On-off control of single-speed motors is conveniently included here)*

Recent studies based upon British conditions have proved that these methods can often result in the best economic proposition of all, and this is particularly true of units needed for the chemical industry. The fans involved are generally smaller and more numerous than those introduced in groups (2) and (3) and, because of this, stepwise control is practicable. Maximum saving of power results and a degree of process control sufficient for most purposes is readily achieved. When additional sensitivity of control is necessary it can be obtained by combining this group with group (1). The result of such a combination gives a degree of control which is comparable with that obtained by using group (2) or (3) methods without being as costly and without the introduction of complex mechanisms.

Finally, some last words of cautionary advice dealing with facts that should be obvious but are often overlooked.

(a) If process temperature control is essential, control of the process fluid rather than the cooling air flow is often simpler and cheaper.

(b) Bad designs causing excessive installed horsepower can never be completely compensated by subsequent power-saving ingenuity.

(c) If only a small amount of power is installed, power-saving devices are uneconomic.

The author wishes to acknowledge the assistance given to him by his colleagues of the Heat Exchange Division of Wellington Tube Works Ltd. and to thank the Directors of that company for permission to publish this article.

Pilot Waste Calcining Facility

THE American Atomic Energy Commission has announced the start of construction on a pilot plant at its National Reactor Testing Station, Idaho, for calcining high-level radioactive liquid waste products.

Fluor Corporation Ltd., Los Angeles, California, commenced excavation work recently on the waste calcination facility as part of a general contract with the Commission for design and construction of waste disposal facilities at the Idaho atomic installation. The firm's basic contract was amended to provide $3,391,700 for construction of the plant, the total cost of which is estimated at $6 million.

The waste calcination facility is designed to reduce high-level liquid radioactive wastes to safer and more storable solids. Laboratory and pilot-plant models demonstrated that the calcining process will reduce the volume of liquid waste to about one-seventh of its present bulk. The new facility, capable of handling one gallon of waste per minute, will provide prototype experience for full-scale plants.

Fluor will construct a waste treatment plant and a concrete storage vault for storing solid plant wastes. The specifications also call for installation of special waste handling equipment for liquids and solids and solid-sampling equipment. Construction is scheduled to be completed by January 31, 1960.

Developed by scientists of Phillips Petroleum Co. and Argonne National Laboratory, the fluidised-bed calcination process is a mechanically simple means of rendering less bulky and significantly less corrosive the fission product solutions resulting from fuel element processing for recovery of unburned uranium. Work to date has indicated that fluidised bed calcining of radioactive wastes should be economically competitive with liquid storage and have less hazard potential.

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DESIGN OF COOLER CONDENSERS

An improved method of design which takes account of total pressure drop on the condensing side

by J. MADEJSKI, Ph.D., M.Sc.

IN this article the term cooler-condenser refers to heat exchangers in which vapour is condensed from mixtures with high concentrations of inert gases. In the process of condensation the mixture is also cooled. Shell and tube exchangers used as vertical condensers are suitable for this purpose; the cooling fluid flows in the shell, its path being directed by baffles. The flow is thus at first cross-current, then co-current or counter-current, then cross-current again and so on with respect to the flow of vapour-gas mixture. When there are no baffles, co-current or counter-current flow will obtain. The last case was analysed by the author[1] and in this paper the method described earlier is improved.

The calculation of heat-transfer conditions in a shell exchanger with vertical tubes cooled in counter- or co-current may be restricted to the analysis of one single tube of inside diameter d and effective length L. Let us suppose that a cooled mixture flows inside the tubes in counter-current with the cooling fluid and from top to bottom, i.e., in co-current with the condensate, which is assumed not to absorb the inert gas. Let the x-axis be directed from top to bottom with $x = 0$ at the inlet of vapour-gas-mixture.

The local conditions of heat transfer at point x are described by the equation:

$$dQ = U(t-\nu)dA \qquad \ldots . (1)$$

The overall thermal resistance, the quantity $1/U$, is the sum of thermal resistances of the outside film of cooling fluid, of scale deposits from cooling fluid and, on the one hand, the tube wall and the thermal resistance of condensate film and equivalent thermal resistance of the gas film, in which diffusion takes place, on the other.

The sum of the first group of resistances will be denoted by $1/U'$, the latter by $1/h$. The coefficient U' can be evaluated readily; the coefficient h will be discussed below in detail.

Heat transferred through the condensate is proportional to the coefficient, denoted by h_c. Heat transfer occurs by conduction if the flow of condensate is laminar. For this case the following formula was proposed by the author:

$$(Nu)_c = \frac{h_c d}{k_c} = f_1 \cdot \left(\frac{p}{p_{BO}} - \frac{p}{p_B}\right)^{-\frac{1}{4}} + f_2 \cdot \left(\frac{p}{p_B} + \frac{1-m^*}{m^*}\right)^{\frac{1}{3}} \cdot \left(\frac{p}{p_{BO}} - \frac{p}{p_B}\right)^{-\frac{1}{4}} \qquad \ldots . (2)$$

where k_c is the thermal conductivity, p_B/p and p_{BO}/p the inert gas content at a given point and at the inlet, $m^* = \frac{M_A}{M_B}$, where M_A, M_B are the molecular weights of vapour and inert gas respectively, and

$$f_1 = 1.10 \cdot \left[\frac{\mu_c}{\mu} \cdot \frac{(Ga)_c}{(Re)_\infty \, m^*}\right]^{\frac{1}{4}}$$

$$f_2 = 0.02 \cdot \left(\frac{\mu}{\mu_c}\right)^{\frac{4}{3}} \frac{\rho_c}{\rho} \cdot (Ga)_c^{-\frac{1}{4}} \cdot [(Re)_\infty \cdot m^*]^{\frac{1}{12}} .$$

In these formulæ

$(Ga)_c = \frac{d^3 g \rho_c^2}{\mu_c^2}$, the Gallilei Number of the condensate;

$(Re)_\infty = \frac{4 M_B N_B}{g \mu \pi d}$, the Reynolds Number of the pure inert gas;

μ, μ_c = the dynamic viscosity of mixture and condensate, respectively;

ρ, ρ_c = the density as above;

g = the acceleration due to gravity; and

N_B = the molal flux of inert gases.

It should be pointed out that expression (2) assumes isobaric flow of the mixture, no pressure drop, and laminar flow of condensate film.

The heat which passes through the condensate film is also transferred through the gas-vapour film; this process occurs partially by convection, with a coefficient h_T, and partially by mass transfer by diffusion through a stagnant inert gas film of an equivalent thickness δ_O.

The first process is negligible compared with the second. Thus the transferred heat dQ is equal to the product of the condensed mass of vapour dN_A and its latent heat r:

$$dQ = M_A \cdot r \cdot dN_A \qquad \ldots . (3)$$

The quantity dN_A may be evaluated from the STEFAN's Law, i.e.:

$$dN_A = \frac{Dp}{RT} \cdot \frac{1}{\delta_D} \ln \frac{p_B}{p_{Bc}} \cdot dA \qquad \ldots . (4)$$

where p_{BC} and p_B denote partial pressures of inert gas near the condensate film and outside the diffusion film respectively.

It therefore follows that:

$$dQ = M_A \cdot r \cdot \frac{Dp}{RTd} \cdot \frac{d}{\delta_D} \ln \frac{p_B}{p_{Bc}} \cdot dA \qquad \ldots . (5)$$

Also

$$dQ = h_D \cdot \triangle t_D \, dA \qquad \ldots . (6)$$

where h_D is the equivalent coefficient of heat transfer and $\triangle t_D$ the respective temperature drops. The latter can be expressed as a function of partial pressure drop of vapour assuming that the mixture is saturated. For this purpose the equation of CLAUSIUS and CLAPEYRON may be used, namely:

Prof. Madejski *has been Professor of Thermodynamics at the Politechnika Gdanska and Director of Heat Division in the Institute of Flow Machines, Polish Academy of Sciences since 1954.*

Symbols Used

A = area;
D = diffusivity;
d = tube diameter;
f_1, f_2 = functions in Equation (2);
g = acceleration due to gravity;
h = film coefficient;
k = thermal conductivity;
L = length of the tube;
M = molecular weight;
$m^* = M_A/M_B$ = ratio of molecular weights of vapour and inert gas respectively;
N = molal flow;
p = total pressure;
p_A, p_B = partial pressures of vapour and inert gas respectively;
Q = heat rate;
$R = 848 \ \frac{\text{kpm}}{\text{kmol °K}}$, $R^* = 1.986 \ \frac{\text{kcal}}{\text{kmol °K}}$ } universal gas constants;
T = absolute temperature;
t = temperature of flowing mixture;
U = overall heat-transfer coefficient;
v = molecular velocity;
W_e = water equivalent;
w = molal velocity;
x, y = co-ordinates;
z = coefficient in $\varphi = (1 + z)\, Q_L$;
δ = thickness of film;
ε = coefficient in Figs. 1 and 2;
ζ = friction number;
θ = dimensionless parameter Equation (23);
ν = temperature of cooling fluid;
μ = viscosity;
ρ = density;
φ = dimensionless area;
ω = dimensionless parameter $\omega = \dfrac{R^* T\, W_e}{N_B\, (1 + z)\, (M_A r)^2}$;
Ga = Gallilei Number;
Nu = Nusselt Number;
Re = Reynolds Number;
Re_∞ = Reynolds Number for dry inert gas; and
Sc = Schmidt Number.

Indexes

A = vapour;
B = inert gas;
c = condensate;
D = diffusion;
i = inside;
k = condensation zone of the condenser;
l = latent;
L = outlet from the cooler-condenser;
m = mixture;
N = according to Nusselt; and
o = inlet; outside.

$dt = \dfrac{R^* T^2}{M_A r}\, d \ln p_A$, where $R^* = 1.986$ kcal/kmol or, for a very small temperature drop $\triangle t_D$.

$$\triangle t_D = \frac{R^* T^2}{M_A r} \ln \frac{p_{AC}}{p_A} \qquad \ldots . (7)$$

In this formula p_{AC} and p_A denote partial pressures of vapour near the condensate film and outside the diffusion film respectively. Assuming no pressure drop in the direction perpendicular to the flow, i.e., to the wall, we obtain:

$$p_{AC} = p - p_{BC}, \; p_A = p - p_B$$

$$\triangle t_D = \frac{R^* T^2}{M_A r} \ln \frac{p - p_{BC}}{p - p_B} \qquad \ldots . (8)$$

and

$$dQ = h_D \cdot \frac{R^* T^2}{M_A r} \cdot \ln \frac{p - p_{BC}}{p - p_B}\, dA \qquad \ldots . (9)$$

From Equations (5) and (9) we obtain:

$$h_D = \frac{(M_A r)^2 Dp}{RR^* T^2 d} \cdot \frac{d}{\delta_D} \cdot \frac{\ln \dfrac{p_B}{p_{BC}}}{\ln \dfrac{p - p_{BC}}{p - p_B}} \qquad \ldots . (10)$$

Thus

$$\frac{1}{h} = \frac{1}{h_D} + \frac{1}{h_C} \text{ and } h = \frac{h_D}{1 + \dfrac{h_D}{h_C}}. \qquad \ldots . (11)$$

The ratio

$$\triangle = \left(\ln \frac{p_B}{p_{BC}}\right) : \left(\ln \frac{p - p_{BC}}{p - p_B}\right)$$

can be calculated from critical tables. For very small partial pressure differences

$$\triangle p_B = p_{BC} - p_B$$

Hence one might assume

$$\triangle \simeq \frac{p - p_B}{p_B}$$

This approximation is not accurate, however, and the following formula should be used

$$\triangle = \left(\frac{p}{p_B} - 1\right) \cdot \varepsilon,$$

where ε is a correction coefficient. The graph ε versus $p/_B p$ is shown in Fig. 1 for mixtures with steam at $p = 1$ atma. The quantity d/δ_D from Equation (10) plays an important role in the mass transfer. From scanty experimental data the author found the following approximate relation[1]:

$$\frac{d}{\delta_D} = \frac{5 + 0.004 \dfrac{p_B}{p}\, (\mathrm{Sc})\, (\mathrm{Re})}{1 + 0.75 \left[\left(\dfrac{p_B}{p}\right)^{\frac{2}{3}} \cdot (\mathrm{Sc})^{\frac{1}{3}} - 1\right]} \qquad \ldots . (12)$$

This formula, however, has not yet been shown to apply to small values of p_B/p. Thus U may be expressed as a function of inert gas content, p_B/p, and the actual molal velocity of the mixture, w.

Let Q be the heat load upon a single tube of the heat exchanger. It consists of the latent heat of condensation Q_L, the enthalpy drop of the gaseous mixture Q_m, and finally the enthalpy drop of the condensate Q_c, namely:

$$Q = Q_L + Q_m + Q_c$$

The terms Q_m and Q_c are comparatively small and their influence may be taken into account by means of a coefficient

$$z = \frac{Q_m + Q_c}{Q_L}$$

hence $Q = (1 + z) \cdot Q_L$.

The coefficient z is a small number and its value may be evaluated from the general balance of the exchanger. On an element of area dA at x there condenses an amount of vapour dN_A. The heat to be removed is:

$$dQ_L = - M_A r dN_A$$

The heat transferred to the cooling agent will be greater, i.e.:

$$dQ = (1 + z)\, dQ_L$$

hence

$$dQ = - (1 + z) M_A r dN_A \qquad \ldots . (13)$$

The heat dQ causes an increase of the temperature of cooling fluid dv. W_e is the water equivalent of cooling fluid for counter-current flow, we obtain

$$dQ = - W_e dv \qquad \ldots . (14)$$

from

$$dQ = - (1 + z)\, M_{Ar} \frac{dN_A}{dt} \,.\, dt. \qquad \ldots . (15)$$

From Equations (14) and (15) it follows

$$d(t - v) = - dQ \,.\, \left[\frac{1}{(1 + z)\, M_{Ar} \dfrac{dN_A}{dt}} - \frac{1}{W_e} \right] \qquad \ldots . (16)$$

which compares with $t - v = \dfrac{1}{U} \cdot \dfrac{dQ}{dA}$. from Equation (1)

The quantity dN_A/dt may now be determined. The flow of vapour N_A and inert gas N_B, the latter remaining constant through the process, are:

$$N_A = \frac{\pi d^2}{4} \cdot \frac{p_A}{RT} \cdot W,$$

and $$N_B = \frac{\pi d^2}{4} \cdot \frac{p_B}{RT} \cdot W = \text{constant},$$

hence

$$N_A = N_B \frac{p_A}{p_B} = N_B \frac{p - p_B}{p_B} = N_B \left(\frac{p}{p_B} - 1 \right),$$

where $p = p_A + p_B$ is the total pressure.
Therefore:

$$\frac{dN_A}{dt} = - N_B \left(\frac{p}{p_B} \right)^2 \cdot \frac{d(p_B/p)}{dt} = \frac{N_B}{p} \cdot \left(\frac{p}{p_B} \right)^2 \cdot \frac{dp_A}{dt} \,.$$

According to the CLAUSIUS—CLAPEYRON equation it should be:

$$\frac{dp_A}{dt} = \frac{M_{Ar}}{R^* T^2} \cdot p_A = \frac{M_{Ar} p}{R^* T^2} \left(1 - \frac{p_B}{p} \right).$$

Thus

$$\frac{dN_A}{dt} = \frac{N_B M_{Ar}}{R^* T^2} \cdot \left(\frac{p}{p_B} \right)^2 \left(1 - \frac{p_B}{p} \right). \qquad \ldots . (17)$$

From $$\frac{dN_A}{d(p_B/p)} = - \left(\frac{p}{p_B} \right)^2 N_B,$$

and Equation (13) we obtain:

$$dQ = (1 + z) M_{Ar}\, N_B \left(\frac{p}{p_B} \right)^2 d(p_B/p). \qquad \ldots . (18)$$

Substitution of Equations (17) and (18) in Equation (16) gives:

$$d(t - v) = -(1+z) M_{Ar}\, N_B \left(\frac{p}{p_B} \right)^2 \left[\frac{R^* T^2}{N_B (1+z) (M_{Ar})^2} \cdot \frac{\left(\dfrac{p_B}{p} \right)^2}{1 - \dfrac{p_B}{p}} - \frac{1}{W_e} \right] d\frac{p_B}{p} \qquad \ldots . (19)$$

and of Equation (18) in $t - v = \dfrac{1}{U} \dfrac{dQ}{dA}$ gives

$$t - v = \frac{1}{U} (1 + z)\, M_{Ar}\, N_B \left(\frac{p}{p_B} \right)^2 \frac{d(p_B p)}{dA} \qquad \ldots . (20)$$

Subsequent substitution of Equation (20) in Equation (19) to eliminate the temperature difference gives

$$\frac{d}{d(p_B/p)} \left[\frac{1}{U} \cdot \left(\frac{p}{p_B} \right)^2 \frac{d(p_B/p)}{dA} \right] = \frac{1}{W_e} \cdot \left(\frac{p}{p_B} \right)^2 - \frac{R^* T^2}{N_B (1 + z)\, (M_{Ar})^2} \cdot \frac{1}{1 - \dfrac{p_B}{p}} \qquad \ldots . (21)$$

where

$$\frac{1}{U} = \frac{1}{h} + \frac{1}{U'} = \frac{1}{U'} \left(1 + \frac{U'}{h} \right).$$

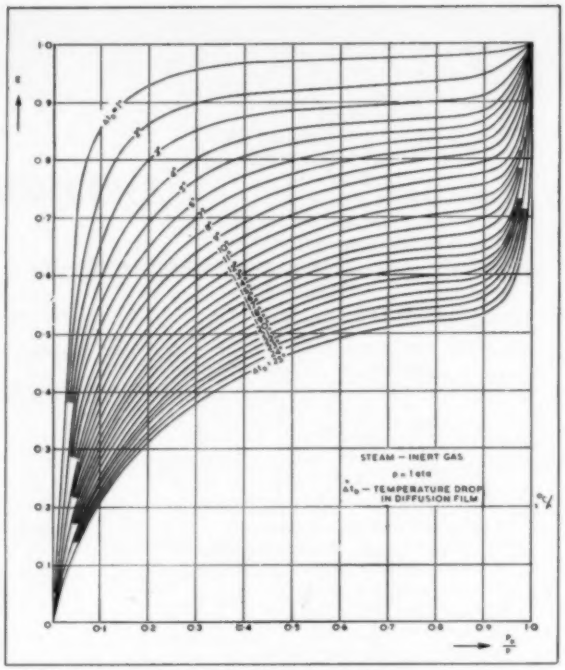

Fig. 1. Correction coefficient ε for different concentrations of inert gas with temperature drop across different films as parameters.

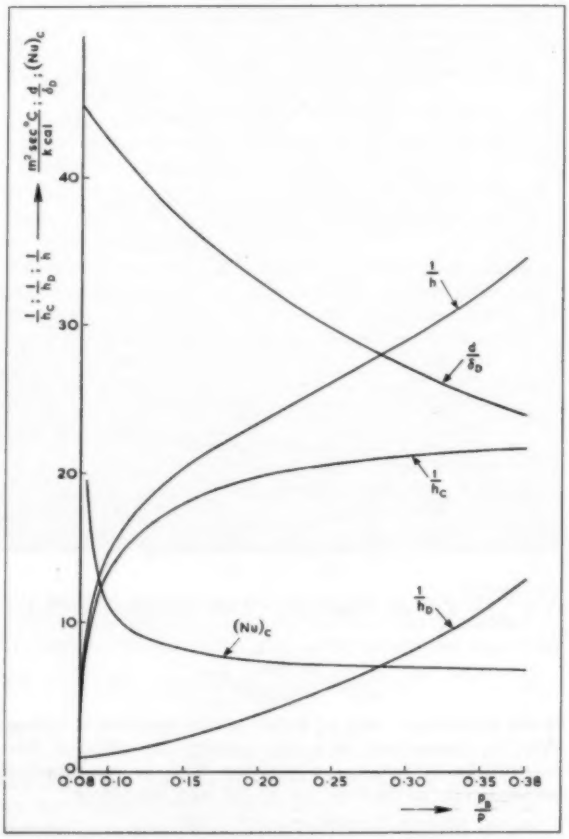

Fig. 2. Design of a cooler condenser. Effect of inerts on film coefficients.

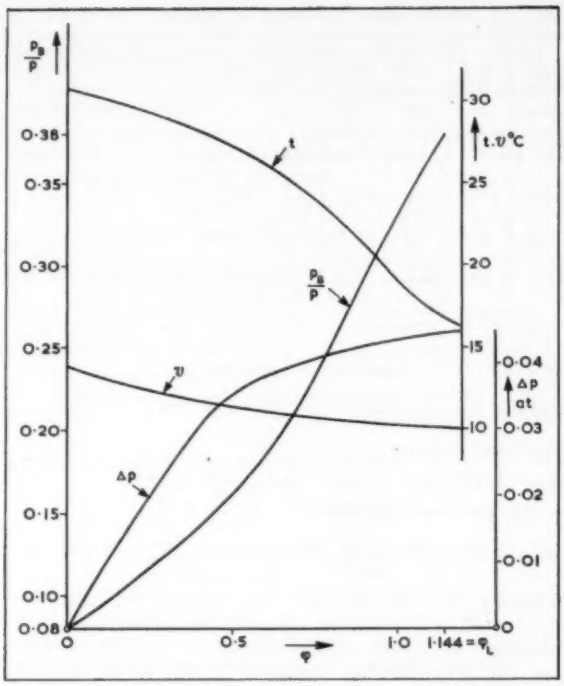

Fig. 3. Design of chlorine condenser. Results of integration of Equation (30). The relationship of p/p_o *to* φ *is also shown.*

It is convenient to write the differential Equation (21) in dimensionless form; for this purpose the following dimensionless variable, in addition to p_B/p, is introduced.

$\varphi = \dfrac{U'A}{W_e}$ and the dimensionless parameter

$$\omega = \frac{R^* T^2 W_e}{N_B(1+z)(M_A r)^2}.$$

Equation (21) becomes:

$$\frac{d}{d(p_B/p)}\left[\left(1+\frac{U'}{h}\right)\left(\frac{p}{p_B}\right)^2 \cdot \frac{d(p_B/p)}{d\varphi}\right] = \left(\frac{p}{p_B}\right)^2 - \frac{\omega}{1-\dfrac{p_B}{p}}$$

Integration gives a first-order differential equation

$$\left(1+\frac{U'}{h}\right)\left(\frac{p}{p_B}\right)^2 \cdot \frac{d(p_B/p)}{d\varphi} = -\frac{p}{p_B} + \omega \ln\left(1-\frac{p_B}{p}\right) + \text{constant} \quad \ldots\ (22)$$

The arbitrary constant in this equation may be evaluated from Equation (20), from which it follows at the inlet ($x = 0$), where $t = t_O$ and $v = v_O$, that

$$\left(1+\frac{U'}{h}\right)\cdot\left(\frac{p}{p_B}\right)^2 \frac{d(p_B/p)}{d\varphi} = \frac{W_e(t_O - v_O)}{N_B(1+z)M_A r} = \theta \quad \ldots\ (23)$$

$$\therefore \quad \theta = -\frac{p}{p_{BO}} + \omega \ln\left(1-\frac{p_{BO}}{p}\right) + \text{constant} \quad \ldots\ (24)$$

Subtraction of Equation (24) from Equation (22) gives

$$\left(1+\frac{U'}{h}\right)\left(\frac{p}{p_B}\right)^2 \cdot \frac{d(p_B/p)}{d\varphi} = \frac{p}{p_{BO}} - \frac{p}{p_B} + \omega \ln \frac{1-\dfrac{p_B}{p}}{1-\dfrac{p_{BO}}{p}} + \theta \quad \ldots\ (25)$$

It should be emphasised that so far it has not been necessary to assume an isobaric flow (p = constant). This was because the preceding treatment dealt not with partial pressure, p_B, but with the gas concentration, p_B/p.

If the pressure drop in the tube is caused by friction at the walls, then:

$$-\frac{dp}{dx} = \frac{\zeta}{d}\cdot\frac{\rho W^2}{2}, \quad \ldots\ (26)$$

where

$$W = \frac{4RTN_B}{\pi d^2 p}\cdot\frac{p}{p_B}, \quad \ldots\ (27)$$

and

$$\rho = \frac{p M_A}{g R T}\left(1+\frac{p_B}{p}\cdot\frac{1-m^*}{m^*}\right). \quad \ldots\ (28)$$

The variable x in Equation (26) is proportional to φ

since

$$\varphi = \frac{U'A}{W_e} = \frac{U'\pi d}{W_e}\cdot x.$$

Thus

$$-\frac{dp}{dx} = -\frac{U'\pi d}{W_e}\cdot\frac{dp}{d\varphi}.$$

From Equations (27) and (28) we obtain finally:

$$-\frac{d(p^2)}{d\varphi} = \frac{16\zeta RTW_e M_A N_B^2}{\pi^2 g d^5 U'}\cdot\frac{p}{p_B}\cdot\left(\frac{p}{p_B}+\frac{1-m^*}{m^*}\right) \quad \ldots\ (29)$$

In this equation the quantity ζ is a function of the Reynolds Number, and, therefore, of the velocity W. Here the friction factor will be assumed independent of Reynolds Number and the variation in absolute temperature will be neglected.

There are thus three equations, namely (25), (27) and (29), to determine the three variables, p_B/p, p, W, as functions of φ. The variable W influences Equation (25) indirectly, as h depends upon the Reynolds Number, and, consequently, upon W.

An exact solution of this group of equations would be troublesome. But as the pressure drop along the tube is kept as small as possible, it will not be necessary to take into account the change in total pressure in Equation (27). Furthermore, with decrease of pressure, which causes an increase of velocity according to Equation (27), the absolute temperature also decreases, and this tends to decrease the effect on velocity. Thus it may be assumed that the velocity W is inversely proportional to the content of inert gas p_B/p. We can, therefore, make the coefficient h_D, and consequently h, a pure function of p_B/p and thus integrate Equation (25). Thus

$$\varphi = \int_{p_{BO}/p}^{p_B/p}\left(1+\frac{U'}{h}\right)\left(\frac{p}{p_B}\right)^2 \frac{d(p_B/p)}{\dfrac{p}{p_{BO}} - \dfrac{p}{p_B} + \omega \ln \dfrac{1-\dfrac{p_B}{p}}{1-\dfrac{p_{BO}}{p}} + \theta} \quad \ldots\ (30)$$

The integration can be performed numerically or graphically. From the relation $p_B/p = 4(\varphi)$, we may integrate Equation (29) and find the pressure drop. The latter may be also found independently by the substitution of $d\varphi$ from Equation (23) into Equation (29) and consequent integration. Hence Equation (29) becomes:

$$-\frac{d(p^2)}{d(p_B/p)} = \frac{16\zeta RTW_e M_A N_B^2}{\pi^2 g d^5 U'}\cdot\frac{\left(1+\dfrac{U'}{h}\right)\left(\dfrac{p}{p_B}\right)^2\left(\dfrac{p}{p_B}+\dfrac{1-m^*}{m^*}\right)}{\dfrac{p}{p_{BO}} - \dfrac{p}{p_B} + \omega \ln \dfrac{1-\dfrac{p_B}{p}}{1-\dfrac{p_{BO}}{p}} + \theta},$$

whence

$$p_O^2 - p^2 = \frac{16\zeta RTW_e M_A N_B^2}{\pi^2 g d^5 U'} \int_{p_{BO}/p}^{p_B/p} \frac{\left(1 + \frac{U}{h}\right)\left(\frac{p}{p_B}\right)^2 \left(\frac{p}{p_B} + \frac{1 - m^*}{m^*}\right)}{\frac{p}{p_{BO}} - \frac{p}{p_B} + \omega \ln \frac{1 - \frac{p_B}{p}}{1 - \frac{p_{BO}}{p}} + \theta} d\frac{p_B}{p} \quad \ldots . (31)$$

Here p_O denotes the initial total pressure of the mixture. The pressure drop from inlet to the point where the inert gas content is p_B/p, becomes thence $\triangle p = p_O - p$.

Condenser for Liquefying Chlorine

A vertical tubular condenser is to be designed for liquefaction of chlorine from saturated mixture at $p = 10$ atma (= 142.1 psi.), consisting of 92% by volume gaseous chlorine and 8% by volume inert gases of molecular weight $M_B = 35$ (approximately 60% of air and 40% of carbon dioxide, no hydrogen. Now $M_A = 70.9$; $\frac{p_{BO}}{p} = 0.08$. The flow of the raw gas is $N_O = 20$ kmol/hr. (= 44.1 lb. mol/hr.). The content of inert gas at outlet should be $p_{BL}/p = 0.38$. One-inch OD 15 BWG steel tubes are to be used arranged on a 1¼-in. triangular pitch. The inner surfaces of the tubes are to be covered with a thin rubber film.

If water is used for cooling, then its inlet temperature for counter-current will be taken, $v_L = 10°C = 50°F$, whereas the outlet temperature will be $v_O = 14°C = 57.2°F$. An arrangement of 224 tubes is to be examined and the tube length and the pressure drop calculated.

SOLUTION

The flow of inert gas through one tube is

$N_B = \frac{(20)0.08}{224} = 7.15 \cdot 10^{-3}$ kmol/hr $= 1.575 \cdot 10^{-2}$ lb. mol/hr.

The mass of chlorine condensed in one tube, therefore, is

$\triangle N_A = 7.15 \cdot 10^{-3} \left(\frac{0.92}{0.08} - \frac{0.62}{0.38}\right) = 7.05 \cdot 10^{-2} \frac{\text{kmol}}{\text{hr.}} =$ 0.1557 lb.mol/hr, and vapour losses are:

$N_{AL} = 7.15 \cdot 10^{-3} \cdot \frac{0.62}{0.38} = 1.166 \cdot 10^{-2} \frac{\text{kmol}}{\text{hr.}} = 2.57 \cdot 10^{-2}$ lb.mol/hr.

For the saturated mixture the inlet temperature $t_O = 30.8°C = 87.5°F$ and outlet temperature $t_L = 16.3°C = 61.3°F$. The corresponding mean latent heat of vaporisation for this range is $r = 59.5$ kcal/kg = 107 Btu/lb. The specific heats for condensate, inert gas and gaseous chlorine are assumed to be 0.215, 0.24, 0.12 kcal/kg°C respectively.

Enthalpy balance:

Latent heat: $Q_L = 7.05 \cdot 10^{-2} (70.9) (59.5) = 8.26 \cdot 10^{-2}$ kcal/sec.

Enthalpy drop of condensate:

$Q_c = 7.05 \cdot 10^{-2} (70.9) (0.215) (30.8 - 16.3) = 0.433 \cdot 10^{-2}$ kcal/sec.

Enthalpy drop of inert gas:

$Q_{m1} = 7.15 \cdot 10^{-2} (35) (0.24) (30.8 - 16.3) = 0.024 \cdot 10^{-2}$ kcal/sec.

Enthalpy drop of outlet vapour:

$Q_{m2} = 1.166 \cdot 10^{-2} (70.9) (0.12) (30.8 - 16.3) = 0.04 \cdot 10^{-2}$ kcal/sec.

Heat load:

$Q = 8.757 \cdot 10^{-2}$ kcal/sec. = 0.347 Btu/sec.

and $z = \frac{(0.433 + 0.024 + 0.04)\ 10^{-2}}{8.757 \times 10^{-2}} = 0.057$

The water required:

$G_w = 2.168 \cdot 10^{-2}$ kg/sec. $= 4.83 \cdot 10^{-2}$ lb./sec.

so that the water equivalent

$$W_e = 2.168 \cdot 10^{-2} \frac{\text{kcal}}{\text{sec.°C}} = 4.83 \cdot 10^{-2} \frac{\text{Btu}}{\text{sec.°F}}$$

Knowing the area of shell free section for one tube (5.03×10^{-4} m²), we may calculate the velocity of water, which is 0.043 m/sec. = 0.141 ft/sec.—a low value. For this case the film coefficient computed by the SIEDER and TATE equation is equal to $158 \frac{\text{kcal}}{\text{m}^2 \text{ hr } °C} = 32.3 \frac{\text{Btu}}{\text{sq.ft°Fhr.}}$, and is also extremely small.

The use of baffles will increase the film coefficient to about

$$1770 \frac{\text{kcal}}{\text{m}^2\text{hr } °C} = 362 \frac{\text{Btu}}{\text{sq. ft hr°F}}$$

Furthermore, assuming the thermal resistances of tube wall, rubber film, and scale deposits from water to be 0.169; 2.57; $1.052 \frac{\text{m}^2 \text{ sec.}}{\text{kcal}}$ °C, respectively we obtain:

$$U = 619 \frac{\text{kcal}}{\text{m}^2 \text{ hr } °C} = 127 \frac{\text{Btu}}{\text{sq. ft hr °F}}.$$

The conditions of heat transfer inside the tube of inside diameter $d = 0.856$ in. = 0.0217 m were calculated using the data for chlorine, taken from Reference 2.

The value

$$\frac{Dp}{RT} = 4.06 \cdot 10^{-7} \frac{\text{kmol}}{\text{m . sec.}}$$

was computed from the formula of GILLILAND. The viscosity μ was assumed according to Reference 3 for mean temperature 25°C = 77°F; it was obtained $\mu = 0.261$ cp $= 2.66 \cdot 10^{-6} \frac{\text{kp sec.}}{\text{m}^2}$ for gaseous chlorine and $\mu = 0.232$ cp $= 2.37 \cdot 10^{-6} \frac{\text{kp sec.}}{\text{m}^2}$ for inert gas. The viscosity of the mixture therefore varies from $2.64 \cdot 10^{-6}$ at inlet to $2.55 \cdot 10^{-6} \frac{\text{kp sec.}}{\text{m}^2}$ at outlet. A mean value $\mu = 2.6 \cdot 10^{-6} \frac{\text{kp sec.}}{\text{m}^2}$ was therefore assumed.

According to these data, the Schmidt Number differs very little from unity.

The Reynolds Number of the inert gas is

$$\text{Re} = \frac{(4.35)7.15 \cdot 10^{-3}(35)}{(9.81)2.6 \cdot 10^{-6}(3.14)(0.0217)(3600)} = 160.$$

The results of the calculations are given in Table 1 and in Fig. 2.

Table 1

p_B/p	0.08	0.10	0.15	0.20	0.25	0.30	0.35	0.38
$(Nu)_c$	∞	10.87	8.14	7.46	7.17	6.98	6.86	6.80
$1/h_c$	0	13.62	18.20	19.85	20.66	21.20	21.60	21.80
d/δ	44.7	42.0	36.7	32.8	29.7	27.2	25.1	24.0
$1/h_D$	0.98	1.33	2.29	3.83	5.64	7.82	10.76	12.94
$1/h$	0.98	14.95	20.49	23.68	26.30	29.02	32.36	34.74

Since the viscosity of liquid chlorine, about 32 cp, is high and the thermal conductivity, about 0.53 $\frac{\text{kcal}}{\text{m hr °C}}$, is low, it is evident that the greatest thermal resistance is that of the condensate.

To determine the heat exchanger area we must first calculate the dimensionless numbers w and ν. Assume a mean absolute temperature $T = 290°K$

$$\omega = \frac{(1.986)(290)^3(2.168)(10^{-2})(3600)}{(70.9)(59.5)^2(1.057)(7.15)(10^{-3})} = 97.1$$

$$\theta = \frac{2.168 \cdot 10^{-3}(30.8 - 14)(3600)}{(70.9)(59.5)(1.057)(7.15)(10^{-3})} = 41.1$$

Equation (30) may be applied to this problem. The results of integration are shown in Fig. 3. Thus, for required $p_{BL}/p = 0.38$, $\varphi = \varphi_L = 1.174$, so that:

$$A = \frac{W_e \varphi_L}{U'} = \frac{(2.168)(10^{-3})(1.144)}{0.172} = 0.144 \text{ m}^2 = 1.55 \text{ sq.ft.}$$

The length of one tube will be therefore

$$L = \frac{0.144}{\pi 0.217} = 2.12\ m = 6.41 \text{ ft.}$$

To determine the pressure drop we evaluate the quantity

$$\frac{16\zeta RTW_e M_A N_B^2}{\pi^2 g d^3 U' p_O^2} \text{ assuming } \zeta = 0.04$$

$$= \frac{(16)(0.04)(848)(290)(2.168)(10^{-2})(70.9)(7.15)(10^{-3})^2}{(3.14^2)(9.81)(0.0217^6)(0.172)(10)(10^4)^2(3600^2)}$$

$$= 1.745 \cdot 10^{-3}$$

Hence, according to Equation (31)

$$1 - \left(\frac{p}{p_O}\right)^2 = 1.745 \times 10^{-3} \int_{0.08}^{0.38} \frac{\left(1 + \frac{U'}{h}\right)\left(\frac{p}{p_B}\right)^3\left(\frac{p}{p_B} - 0.507\right)}{56.6 - \frac{p}{p_B} + 97.1 \ln \frac{1 - \frac{p_B}{p}}{0.92}} d\frac{p_B}{p}$$

The relation p/p_O versus φ is also shown in Fig. 3. The pressure drop in the tubes is thus $\triangle p = 0.044$ atm. $= 0.626$ psi.

Of course, other alternatives would be calculated in practice and the most suitable arrangement should be chosen. For example, it was found that decreasing the number of tubes to 112 caused an increase of area of about 10% and a pressure drop of about 0.4 atm.

REFERENCES

1. Madejski, J. Uber die Wärmeübertragung bei der kondensation von Dämpfen in Anwesenheit inerter Gase, Chemie-Ing.-Technik, 29 Jahrgang 1957, Nr. 12, s. 801.
2. Ullmann's Encyklopaedie der Technischen Chemie Urban und Schwarzenberg, München, 1951.
3. Coulson, J. M., and Richardson, I. F., "Chemical Engineering, Pergamon Press, London, 1957.
4. Ed. Emblik, Uber die Verflüssigung von Chlor durch Kälte, Kältetechnik, Band 9 (1957), Heft 3, s. 72.
5. Ost-Rassow, Lehrbuch der chemischen Technologie, 26. Auflage, 1955.

Insulating Bricks from Mica Scrap

New Material Developed at the Indian Central Glass and Ceramic Research Institute

INDIA supplies about 80% of the world's requirements of sheet mica. In the process of rifting the mica into sheets, however, about 85-90% of the mined mica is lost as scrap and the total recovery of processed mica for industrial uses constitutes hardly 10%. There is a further loss of about 45-60% of this processed mica during the manufacture of various mica parts. India, therefore, has a large accumulation—over 50,000 tons annually—of scrap mica which is so far considered waste. During the course of investigations on the utilisation of this scrap at the Indian Central Glass and Ceramic Research Institute, Jadavpur University, Calcutta, a method has been developed for producing mica heat-insulating materials which may be formed cheaply into bricks, slabs and various other shapes.

The bricks are light and porous and possess a relatively high insulating value. In most of their properties, like density, porosity, strength, thermal conductivity and re-heat shrinkage, they are comparable to vermiculite bricks; in fact, their re-heat shrinkage is more favourable (see table).

Properties of Mica and Vermiculite Bricks Compared

Properties	Mica	Vermiculite
1. Bulk density (lb./cu. ft)	35-45	35-45
2. Cold crushing strength (psi)	100-150	100-125
3. Thermal conductivity (Hot face temp. 500°C)	0.9 to 1.3	0.93 to 1.3
4. Air permeability cc/sec./ cm. cu./in. water pressure	3.1	6.2
5. Percentage re-heat shrinkage (24 hours soaking) at 865°C	(a) 0.105	(a) 0.82
at 1060°C	(b) 2.83	(b) The bond fails
6. Percentage shrinkage under load (1 ton/sq. ft) at 1000°C for 1½ hr ...	7.6	7.2

Performance trials for thermal insulation of mica bricks have been conducted on both laboratory and industrial furnaces and have also yielded highly satisfactory results. Even after continuous use for one year the insulating value is reported not to have deteriorated. The use of such bricks on a muffle furnace brought about a fuel saving of 30-40%. When the door of a reverberatory furnace was backed by the bricks, heat radiation from it was reduced to such an extent that the workers could easily work nearby, whereas formerly it was impossible to approach more closely than 10 ft. Other industrial uses suggested for mica bricks include cold storage insulation, and light-weight and sound-absorbing structural units.

All of the raw materials for the new process are available in India and no special equipment is required for beginning manufacture. Whereas standard size vermiculite bricks cost, on average, about 1 to 1.25 rupees (1s. 6d. to 1s. 10d.) per brick, the cost of production of a mica brick is expected to be about 5-6 annas (little over 5d.).

A factory has already been set up in Rajasthan for manufacturing mica bricks. Its initial capacity is 2500 bricks a day and this is expected to be doubled within a year.

A Guide to the Availability of Heat-exchange Equipment. Based on Information Supplied by Manufacturers

Heat Exchangers

Shell and tube; reboilers

Maximum Size or Capacity (In diameter of shell or tube plate, unless otherwise stated)	Materials of Construction	Can the Design be Determined by the Client?	Codes of Mechanical Design	Manufacturer
3 ft	SS, aluminium, three other selected metals	Yes	Generally to BS1500 (1949)	A.P.V. Co. Ltd.
19 ft 6 in.	Ferrous and non-ferrous metals	Yes	British, Lloyd's AOTC, Admiralty general, ASME, TEMA, A.Bur.Ship.	A.E.I. Turbine Generator Division
Standard 48-in. Non-standard, as required	All weldable metals	Yes	All	Ashmore, Benson, Pease & Co.
To meet requirement of chemical industry, petroleum refineries, and up to nuclear power plant capacities	Ferrous, non-ferrous, low alloys, austenitic steels, as required	Yes	TEMA, ASME, BS 1500, AOTC, Lloyd's, Netherlands	Babcock & Wilcox Ltd.
42 in.	CS alloy steel, brass, bi-metal	Yes	ASME, TEMA, BS1500	Henry Balfour & Co. Ltd.
Plain or turbofinned, any size or capacity	Most	No	BS	The Beverley Chemical Engineering Co. Ltd.
6 ft	CS, SS, aluminium, brasses and bronzes, cupro-nickel	Yes	ASME, TEMA, API and all other recognized codes	Birwelco Ltd.
5 ft, usually, but over 10 ft possible	Copper, MS, SS, brass, phosphor-bronze, aluminium	Yes	Normally BS1500, but can be determined by client	Blairs Ltd.
36 in.	CS, SS, aluminium, brasses and bronzes, cupro-nickel	Yes, although normally rated by manufacturer	ASME, TEMA, API and other codes including manufacturers' standards	Brown Fintube (G.B.) Ltd.
6 ft (reboiler 4 ft)	All forms of ferrous and non-ferrous	Yes	TEMA, BS2041, EEUA, ASME, BS1500, etc.	Buckley & Taylor Ltd.
48 in.	SS, stainless clad steel, Monel, nickel, aluminium	Yes	BS2041, TEMA, EEUA	Burnett & Rolfe Ltd.
2-9½ in. o.d. (200 tons/hr)	Shell, boiler quality steel 26/32; water box, gunmetal, cast iron or cast steel; tube plate, rolled naval brass; tubes, aluminium, brass	No		George Clark & North Eastern Marine (Sunderland) Ltd. (Richardson Westgarth Group)
72 in.	CS, Coltuf low temp. steel, stainless iron, SS, lower chrome steels, non-ferrous	Yes, but client's design subject to manufacturer's check and approval	ASME, TEMA, SOD, BS1500 and client's specifications	A. F. Craig & Co. Ltd.
6-ft tube plate	MS, SS, non-ferrous alloys	Yes	BS1500, ASME	John Dore & Co. Ltd. John Dore Engineering Ltd.
Tube place up to 5 ft Shells up to 15 ft	Stainless, low-alloy, carbon steels. Non-ferrous alloys	Yes	BS1500, BS2041, ASME, UPV, Sec.8, ASME, power boilers, Sec. 1, TEMA standards and other foreign codes	W. J. Fraser & Co. Ltd.

Shell and tube; reboilers, cont.

3 ft	MS, SS, Monel, aluminium	Yes	ASME, BS1500, TEMA	T. Giusti & Son Ltd.
No limit	SS, alloy, carbon, steels, nickel, aluminium alloy and nickel-clad carbon steels	Yes. Thermal design not normally supplied	ASME, BS1500, TEMA	G. A. Harvey & Co. (London) Ltd.
60 in. tube plate	Ferrous, including SS. Non-ferrous	Yes	TEMA, BS2041, ASME, BS1500 or as required	Head Wrightson Processes Ltd.
30-in.	Weldable metals	Yes	TEMA, ASME, BS1500, BS2041, AOTC, Lloyd's class 2	Heat Transfer Ltd.
Any size	Aluminium, tantalum, titanium, zirconium	Yes		W. C. Heraeus Platinschmelze G.m.b.H. *Agents:* New Metals & Chemicals Ltd.
4 ft 6 in. shell	MS, SS, CI. Shell and headers, MS, SS, bi-metal, non-ferrous tubes and plates	Yes	AOTC class 2, Lloyd's class 2, BS1500, BS2041, TEMA	Holden & Brooke Ltd.
4 ft.	MS	Yes, by arrangement	BS1500, BS2041, Lloyd's Class 2	Holmes, W. C., & Co. Ltd.
25 ft dia. 3 in. thick	MS, SS	No	BS	International Combustion Ltd.
Various	SS	Yes	BS1500, ASME	A. Johnson & Co. (London) Ltd.
38 in shell dia.	Keebush carbon	Yes when manufacturer's design not applicable	BS1500	Kestner Evaporator & Engineering Co. Ltd.
72 in.	Copper	Yes	BS853	Henry Mainwaring (Coppersmiths) Ltd.
18 in.	Titanium, light alloy	Yes	As required	Marston Excelsior Ltd.
26 tons weight	SS, Monel, nickel and other corrosion resistant steels and alloys	Yes	TEMA, (R.C.&A.), BS1500, BS2041, EEUA, etc.	Metal Propellers Ltd.
9 ft shell dia.	MS, SS.	Yes	All	Newton Chambers & Co. Ltd.
Any size	MS, austenitic stainless steel, aluminium, copper	Capacity only, but design can be supplied for fabrication by others	TEMA, BS1500, BS2041 ASME	Petrocarbon Developments Ltd.
12 in. dia. shell 25 sq. ft	Heat-resisting glass	No		Q.V.F. Ltd.
Shell and tube 44 in. i.d. shell, 16 ft tube length	Ferrous or non-ferrous metals	No	BS1500, TEMA, ASME, UPV	Serck Radiators Ltd.
5 ft dia.	Steel, BS14, ASTM A201. Alloy steels, stainless steel	Yes	ASME, TEMA	Simmons & Hawker Ltd.
6 ft	MS, SS, Monel, nickel, aluminium	Yes	ASME, BS1500	Leonard Smith (Engineers) Ltd.
8½-in. calorifier	Ferrous			Spirax Sarco Ltd.

Shell and tube; reboilers, cont.

Maximum Size or Capacity (In diameter of shell or tube plate, unless otherwise stated)	Materials of Construction	Can the Design be Determined by the Client?	Codes of Mechanical Design	Manufacturer
Any reasonable size	SS, etc.	Yes	BS	Taylor Rustless Fittings Co. Ltd.
Shell 2 ft 3 in. int. dia.	MS, SS	Chemical design only	AOTC	Thompson Bros. (Bilston) Ltd.
Normal industrial and special cases	Ferrous and non-ferrous	Yes	TEMA, ASME, BS	John Thompson Group
Also feed heaters, condensers, etc. To suit requirements.	Ferrous or non-ferrous, depending on operating conditions	Yes	All	G. & J. Weir Ltd.
Up to 30 tons	Mild, alloy, low chrome, SS, Monel, aluminium, bronze, cupro-nickel	Yes	ASME, TEMA, BS1500 or clients' requirements	Foster Wheeler Ltd.
6 ft	Any metals	No	Any	Heat Exchange Division, Wellington Tube Works Ltd.
Max. shell dia.=60 in. or larger (Reboilers: Max. shells dia.=75 in. or larger)	Steel—Carbon, low alloy and stainless Non-ferrous—Aluminium, brass, etc.	Yes Yes	TEMA, classes R.C. and A, BS2041 Used in conjunction with BS1500 or ASME, pressure vessel codes	Whessoe, Ltd.
5 ft	All carbon steels, alloys, etc.	Yes	BS, Lloyd's, ASME, TEMA, AOTC	White's of Hebburn (Engineers) Ltd.
Any capacity to suit customers' requirements	Fabricated steel or C.I. tubes	Yes	BS1500, AOTC, Lloyd's, ASME	Worthington-Simpson Ltd.

Air-cooled

Maximum Size or Capacity (in Btu an hour except where otherwise stated)	Materials of Construction	Can the Design be Determined by the Client?	Codes of Mechanical Design	Manufacturer
57 million (in single unit)	All ferrous and non-ferrous metals	Yes	BS, Lloyd's, AOTC, Admiralty General Specification, ASME	A.E.I., Turbine Generator Division
No limit	MS or alloy steel	Yes	None	Babcock & Wilcox Ltd.
10,000–100,000	CI, carbon steel, alloy steel	Yes		Henry Balfour & Co. Ltd.
Max. bundle size 8×30 ft	Headers in SS, CS, and lower chrome group. Tube finning in aluminium	No	ASME	A. F. Craig & Co. Ltd.
To client's requirements	Steels, carbon and stainless, aluminium, brasses, bronzes, cupro-nickel, aluminium fins on carbon steel	Yes	ASME, TEMA, API, and others, including manufacturers'	Brown Fintube (G.B.) Ltd.
3 million	MS, SS, non-ferrous alloys	Yes	BS1500, ASME	John Dore & Co. Ltd. John Dore (Engineering) Ltd.

Air-cooled, cont.

20 million or more	Stainless, low alloy, carbon steels. Non-ferrous alloys	Yes	BS1500, BS2041, ASME, UPV, Sec. 8, and power boilers, sec. 2. Other foreign standards	W. J. Fraser & Co. Ltd.
No limit	CS, alloy steel, SS	Yes	ASME	G. A. Harvey & Co. (London) Ltd.
As required	Ferrous including SS, non-ferrous	Yes	ASME, BS1500 or as required	Head Wrightson Processes Ltd.
10 million—water 3 million—hydrocarb.	Weldable metals	Yes	TEMA, ASME, BS1500, BS2041, AOTC, Lloyd's class 2	Heat Transfer Ltd.
1 million	MS	Yes, by arrangement		W. C. Holmes & Co. Ltd.
50 million	MS or SS	No	British	International Combustion Ltd.
500 million	Light alloy	Yes	As required	Marston Excelsior Ltd.
25 million 15 ft 6 in. wide, 27 ft long	Steel tubes steel wound with aluminium ribbon	No	ASME, UPV	Serck Radiators Ltd.
1 million	MS, SS, Monel, nickel	Yes	ASME, BS1500	Leonard Smith (Engineers) Ltd.
Normal industrial and special cases	Ferrous and non-ferrous	Yes	TEMA, ASME, BS	John Thompson Group
Unlimited	Any metals	No	Any	Heat Exchange Division, Wellington Tube Works Ltd.
Composed of elements each having approx. max. plan size 8×30 ft	Carbon low alloy and stainless steels. Aluminium, brass	Yes	TEMA, RCA, BS1500, BS2041, ASME	Whessoe Ltd.
5 million Btu per unit	All carbon steels, alloys, etc.	Yes	BS, ASME, TEMA	Whites of Hebburn (Engineers) Ltd.

Annular

Maximum Size or Capacity (in sq. ft unless otherwise stated)	Materials of Construction	Can the Design be Determined by the Client?	Codes of Mechanical Design	Manufacturer
50–500	Carbon steel, alloy steel	Yes	—	Henry Balfour & Co. Ltd.
Turbofin and Quadtube elements assembled to any capacity	Most	No		The Beverley Chemical Engineering Co. Ltd.
1000 or more	Copper, MS, SS, brass, phosphor-bronze, aluminium	Yes	Normally BS1500 but can be determined by client	Blairs Ltd.
8000 (extended surface or bare tube)	Carbon and stainless steels, aluminium, brasses and bronzes, cupro nickel	Yes	ASME, TEMA, API and others including manufacturers'	Brown Fintube (G.B.) Ltd.
73 sq. ft element	CS, Coltuf low-temp. steel, stainless iron, SS. lower chrome steels, non-ferrous	Yes, but client's design subject to manufacturer's check and approval	ASME, TEMA, SOD, BS1500, and client's specifications	A. F. Craig & Co. Ltd.

Annular, cont.

Maximum Size or Capacity (in sq. ft unless otherwise stated)	Materials of Construction	Can the Design be Determined by the Client?	Codes of Mechanical Design	Manufacturer
1500	MS, SS, non-ferrous alloys	Yes	BS1500	John Dore & Co. Ltd. John Dore Engineering Ltd.
As required	Stainless, low-alloy, carbon steel, non-ferrous alloys	Yes	BSS1500, 2041, ASME, UPV, Sec. 8, and power boiler sec. 1. Other foreign standards	W. J. Fraser & Co. Ltd.
400	MS, SS, Monel, aluminium	Yes		T. Giusti & Son Ltd.
As required	Ferrous including SS, non-ferrous	Yes	ASME, BS1500, or as required	Head Wrightson Processes Ltd.
Any, in increments of 12 sq. ft max.	Weldable metals	Yes	TEMA, ASME, BS1500, 2041, AOTC, Lloyd's class 2	Heat Transfer Ltd.
Any size	Aluminium, tantalum, titanium, zirconium	Yes		W. C. Holmes & Co. Ltd.
Unit size 1000 sq. ft	All Cl	Arrangement only		W. C. Heraeus Platinschmelze G.m.b.H. *Agents:* New Metals & Chemicals Ltd.
140	Copper	Yes	BS1566	Henry Mainwaring (Coppersmiths) Ltd.
26 tons weight	SS, Monel, nickel and other corrosion-resistant steels and alloys	As above	ASME, BS1500, AOTC, Boiler Insurance, Lloyd's 2 etc.	Metal Propellers Ltd.
2000	Cl	No		Newton Chambers & Co. Ltd.
Any size	MS, austenitic SS, aluminium, copper	Capacity only. Design can be supplied for fabrication by others	TEMA, BS1500, BS2041, ASME	Petrocarbon Developments Ltd.
50,000	Non-ferrous ribbon wound tubes	No	AOTC	Serck Radiators Ltd.
To suit client	SS, etc.	Yes	British	Taylor Rustless Fittings Co. Ltd.
10,000	MS, SS, Monel, nickel, aluminium	Yes	ASME, BS1500	Leonard Smith (Engineers) Ltd.
Normal industrial and special cases	Ferrous and non-ferrous	Yes	TEMA, ASME, BS	John Thompson Group
Multiples of 16 sq. ft (plain tube) or 90 sq. ft (finned)	Mild and alloy steel	Yes	ASME, BS1500, or clients' requirements	Foster Wheeler Ltd.
15 sq. ft/unit	All carbon steels, alloys, etc.	Yes	BS, ASME, TEMA, AOTC	Whites of Hebburn (Engineers) Ltd.

Serpentine, cascade

100–1500	Cl, CS	Yes		Henry Balfour & Co. Ltd.
1000 or more	Copper, MS, SS, brass, phosphor bronze, aluminium	Yes	Normally BS1500, but can be determined by client	Blairs Ltd.

Serpentine, cascade, cont.

19 sq. ft/element		Yes		A. F. Craig & Co. Ltd.
3000	MS, SS, non-ferrous alloys	Yes	BS1500	John Dore & Co. Ltd. John Dore Engineering Ltd.
As required	Stainless, low alloy, carbon steels. Non-ferrous alloys	Yes	BS1500, BS2041, ASME, UPV, Sec. 8, and power boilers, Sec. 1. Other foreign standards	W. J. Fraser & Co. Ltd.
400	MS, SS, Monel, aluminium	Yes		T. Giusti & Son Ltd.
As required	Ferrous, including SS, Non-ferrous	Yes	ASME, BS1550, or as required	Head Wrightson Processes Ltd.
Any size	Aluminium, tantalum, titanium, zirconium	Yes		W. C. Heraeus Platinschmelze, G.m.b.H. *Agents:* New Metals & Chemicals Ltd.
Unit size 1000	Cl, MS	Yes by arrangement		W. C. Holmes & Co. Ltd.
26 tons weight	SS, Monel, nickel and other corrosion-resistant steels and alloys	Yes		Metal Propellers Ltd.
No limit	MS, Cl	Partly		Newton Chamber & Co. Ltd.
As required	Acid-resisting lead coils	Yes	As desired	Nordac Ltd.
Any size	MS, austenitic SS, aluminium, copper	Capacity only. Design can be supplied for fabrication by others	TEMA, BS1500, BS2041, ASME	Petrocarbon Developments Ltd.
Unlimited	Heat-resisting glass	Yes		Q.V.F., Ltd.
250	Steel tube—API 5L	Yes	ASA, B31	Simmons & Hawker Ltd.
5000	MS, SS, Monel, nickel	Yes	ASME, BS1500	Leonard Smith (Engineers) Ltd.
To suit client	SS, etc.	Yes	British	Taylor Rustless Fittings Co. Ltd.

Compact surface

Maximum Size or Capacity (in area/cu. ft, unless otherwise stated)	Materials of Construction	Can the Design be Determined by the Client?	Codes of Mechanical Design	Manufacturer
40 sq. ft/cu. ft	SS, CS	Yes	BS1500, BS2041, ASME, UPV, Sec. 8, and power boiler, Sec. 1. Other foreign standards	W. J. Fraser & Co. Ltd.
Any size				W. C. Heraeus Platinschmelze G.m.b.H. *Agents:* New Metals & Chemicals Ltd.
250,000 sq. ft	MS or MS copper chrome	No	British	International Combustion Ltd.

Compact surface, cont.

Maximum Size or Capacity (in area/cu. ft, unless otherwise stated)	Materials of Construction	Can the Design be Determined by the Client?	Codes of Mechanical Design	Manufacturer
3000 sq. ft (24 in. dia. × 24 ft long) Shell and tube oil heater	Aluminium alloy intrusions; also steel tubular	No	Various	International Combustion Ltd.
450 sq. ft	Light alloy, MS, titanium, copper, SS	Yes	To be agreed	Marston Excelsior Ltd.
2.5 sq. ft/cu. ft approx. (500 ft H.T.A.)	Graphite	No	Pressure vessel codes not applicable	Powell Duffryn Carbon Products Ltd.
70 sq. ft per cu. ft 12 in. dia. × 5 ft tube length. Guided flow heater	Ferrous	No	BS1500	Serck Radiators Ltd.
150 sq. ft/cu. ft	Cu, Al, brass, Al alloys	Yes	BS, ASME, TEMA	Whites of Hebburn (Engineers) Ltd.

Plate

Maximum Size or Capacity (sq. ft)	Materials of Construction	Can the Design be Determined by the Client?	Codes of Mechanical Design	Manufacturer
1200, in single units	SS, titanium, Monel and other selected metals	No		A.P.V. Co. Ltd.
4300	Various SS, titanium, cupro-nickel	No		Alfa-Laval Co. Ltd.
As required	CS	Yes	BS1500, BS2041, ASME, UPV, Sec. 8, and power boilers, Sec. 1. Other foreign standards	W. J. Fraser & Co. Ltd.
Al, max. width 10 ft; Ta, 3 ft; Ti, 4 ft; Zr, 4 ft				W. C. Heraeus Platinschmelze G.m.b.H. *Agents:* New Metals & Chemicals Ltd.
250,000 500,000 (air to gas)	MS and MS copper chrome	No No	British Various	International Combustion Ltd.

Other types, etc.

Type and Maximum Size or Capacity	Materials of Construction	Can the Design be Determined by the Client?	Codes of Mechanical Design	Manufacturer
Spiral plates, 2000/2500 in single units	MS, SS, Monel and other selected metals	No	Generally to BS1500 (1949)	A.P.V. Co. Ltd.
Tubular, 484 sq. ft	Steel	Modifications to suit individual requirements can be made		Alfa-Laval Co. Ltd.
Annular (mechanical type), 25 sq. ft	SS, nickel MS and other materials	Not normally. Test facilities available	BS	Baker Perkins Ltd.

Other types, etc. cont.

Mechanical, 100 sq. ft	SS, nickel, MS and other normal constructional materials	Not normally. Test facilities available	BSS or ASME where applicable	Baker Perkins Ltd.
Indirect fired heaters up to 200 million btu/hr.	CS, low chrome, SS, special alloys	No	Manufacturers' standards and all recognised codes	Birwelco Ltd.
Any	Any metal of construction	Each unit is tailor made	Any	Bennett, Sons & Shears Ltd.
Extended surface in direct fired heaters up to 5 million Btu/hr	CS, SS	No	Manufacturers' standards and recognised codes where applicable	Brown Fintube (G.B.) Ltd.
Special designs to clients' requirements				John Dore & Co. Ltd. John Dore Engineering Ltd.
Aftercoolers, 50 to 5000 cfm up to 250 psi W.P.	MS casing, brass tubes	Yes	All codes up to Class 2A	Fraser & Fraser Ltd.
To client's design				M. & W. Grazebrook Ltd.
Nuclear-power station main heat exchanger, 20 ft. shell dia. or larger	Ferrous	Yes	ASME, BS1500, or as required	Head Wrightson Processes Ltd.
Direct-fired furnaces, 1 to 200 million Btu/hr	Ferrous, including stainless	Yes	ASME, BS1500, or as required	Head Wrightson Processes Ltd.
Hairpin reboilers	Aluminium, tantalum, titanium, zirconium	Yes		W. C. Heraeus Platinschmelze G.m.b.H. *Agents:* New Metals & Chemicals Ltd.
Heated or cooled flight conveyor, 500 sq. ft	MS, SS	No		W. C. Holmes & Co. Ltd.
Manufactured to customer's designs and requirements				Horseley Bridge & Thomas Piggott, Ltd.
Tubular, 250,000 sq. ft	MS	No	British	International Combustion Ltd.
Votator scraped surface heat exchangers, 60 sq. ft	SS, nickel, carbon steels	Yes	BS1500, API, ASME	A. Johnson & Co. (London), Ltd. under licence
Poly blocks with two groups of flow passages, 37.6 sq. ft up to about 60,000 gph	Graphite with metal casing	Standard unit designs		Robert Jenkins & Co. Ltd.
Exchangers designed when part of complete plants being engineered				Kellogg International Corp.
100,000 sq. ft	Non-ferrous finned tube	Yes	As required	Marston Excelsior Ltd.
Liquid/liquid; condensers, etc., 26 tons weight	SS, Monel, nickel and other corrosion-resistant alloys	Yes	TEMA (R.C.&A), BS1500, BS2041, EEUA, etc.	Metal Propellers Ltd.
Thermagrid tray (with mass transfer), 130 sq. ft per tray	All wrought weldable metals	No	ASME, BS1500, AOTC Boiler Insurance, Lloyd's 2, etc.	Metal Propellers Ltd.
30 million Btu/hr per unit	Direct contact gas/liquid materials as required	No		Nordac Ltd.

Other types, etc., cont.

Type and Maximum Size or Capacity	Materials of Construction	Can the Design be Determined by the Client?	Codes of Mechanical Design	Manufacturer
Cross-countercurrent Regenerators—ribbon packed —pebble packed	Copper MS, SS, aluminium, copper Refractory lined if required	Capacity only. Design can be supplied for fabrication by others	TEMA, BS1500, BS2041, ASME	Petrocarbon Developments Ltd.
Jacketed coil type units up to 60 sq. ft can be combined	Heat-resisting glass	No		Q.V.F. Ltd.
Coil, 6 in. dia.	Steel or alloy tube	Yes	B31, ASA	Simmons & Hawker Ltd.

Other types, etc., cont.

Laminated plate design. 1 unit 1500 sq. ft. Arranged in series or parallel, any size up to 10000 sq. ft	Shell of mild or stainless steel. Laminated plates of stainless steel	No	Any code depending on clients' country prescriptions. Lloyd, ASME, DIN, etc.	A. B. Ramèn, Patentee, Stockholm. *British agent:* Stainless Steels Vessels (London) Ltd.
Evaporators: submerged tube, multiflash, thermo-compression	Ferrous or non-ferrous			G. & J. Weir Ltd.
Heat exchangers are designed for special conditions				Simon-Carves Ltd.
Finned tube, 6 ft	Any metals	No	Any	Heat Exchange Division, Wellington Tube Works Ltd.

High-temperature Systems

Capacity Range	Maximum Operating Temperature	Heating Medium	Manufacturer
250,000 to 1,500,000 Btu/hr, each capacity being variable through a 5–1 range	300°C	Specially-prepared mineral oil	Beverley Chemical Engineering Co. Ltd.
Up to 5,000,000 Btu/hr	1200°F fluid outlet	Indirect fired	Brown Fintube (G.B.) Ltd.
100,000 to 200 million Btu/hr	1800°F fluid outlet	Indirect-fired. Special systems for various media including Dowtherm hot oil, Araclor, etc.	Birwelco Ltd.
9000 to 1,800,000 Btu head output. For larger output standard units can be coupled together	350°C	Dowtherm (vapour or liquid phase heating)	W. J. Fraser & Co. Ltd.
1 to 50 million Btu/hr heat absorption	750°F fluid temperature	Dowtherm or heat transfer oil	Head Wrightson Processes Ltd.
Any size	Aluminium 200°C Tantalum 300°C Titanium 350°C Zirconium 350°C	Steam, hot water, or oil	W. C. Heraeus Platinschmelze G.m.b.H. *Agents:* New Metals & Chemicals Ltd.
Based on a maximum surface of approx. 5000 sq. ft per unit	600°F	Steam, high-pressure hot water, hot oil, other heat-transfer mediums	Holden & Brooke Ltd.
Standard units oil or gas fired ½ million to 4 million Btu/hr Electrical 6 kW to 120 kW. Larger sizes also available	900°F 480°C	Dowtherm, hydrocarbon oils, hot salt eutectics, organo-silicate liquids, and other organic media	Hygrotherm Engineering Ltd.

High-temperature Systems, cont.

10 million Btu/hr	1650°F	Coal oil or gas	International Combustion Ltd.
20,000 to 8 million Btu/hr	372°C 700°F	Perolene	Kestner Evaporator & Engineering Co. Ltd.
20,000 to 8 million Btu/hr	315°C 600°F	Mineral and high temperature oils	
0 to 480 kW	500°C 932°F	Electricity/immersion, Kestner patent Isolectric	
0 to 400 kW	500/600°C 932/1112°F	Electricity/Induction. Kestner Wild-Barfield patent induction	
0 to 30 kW	250°C 482°F	Electricity/low voltage. Kestner low voltage (patents applied for)	
Inka radiation type to suit requirements	Preheating air up to 850°C	Products of combustion from liquid, solid or gaseous fuels	Newton, Chambers & Co. Ltd.
Needle convection type to to suit requirements	Preheating air up to 650 °C	Products of combustion from liquid, solid or gaseous fuels	
Struthers Wells fired heaters and indirect heating systems	Dependent on fluid being heated	Heaters fired with liquid or gaseous fuel indirect systems using heat-transfer oils, Dowthern, molten salts, or liquid metals.	
10,000 to 8 million Btu/hr. Electrically heated or oil fired	350°C	Diphyl or hot oil	Petrocarbon Developments Ltd.

High-temperature Systems, cont.

4 to 500 sq. ft HTA	180°C	High pressure hot water or steam	Powell Duffryn Carbon Products, Ltd.
Individual units of any capacity up to 10 million Btu/hr. Electricity, oil gas heated	Depends on heating medium. With Dowtherm A up to 750°C	Any medium in the liquid or vapour phase	Rose, Downs & Thompson Ltd. under licence from Hch. Bertrams Ltd.
Any capacity using tubes in the range ¼–16 in. dia.	1000°F	Steam, water, oil	Simmons & Hawker Ltd.
100,000 to 10 million Btu/hr	180°C	Water	Sturtevant Engineering Co. Ltd.
Steam generators 1000lb/hr upwards Fired air heaters	1100°F 1400°F	Any fuel	John Thompson Water Tube Boilers Ltd.
To suit requirements	Governed by the heating medium	Steam or hot gases	Tomlinsons (Rochdale) Ltd.
Units can be manufactured to suit client's system requirements			G. & J. Weir Ltd.
From 2.5 million Btu/hr approx. 0.05-26.0 million Btu/hr	1100°F approx. 700°F	Direct fired Dowtherm	Foster Wheeler Ltd.
Any capacity to suit requirements	To suit requirements	Steam, water, oil	Worthington Simpson Ltd.

Finned Tubing

Tube Sizes	Surface Area Per Foot	Materials of Construction	Manufacturer
Helically finned 1½, 2 in. or greater o.d.	Fin height ½–1 in.; thickness $\frac{1}{16}$–$\frac{1}{28}$ in. Fins pitched at up to six per in.	MS. Fins semi-automatically welded to tube	Babcock & Wilcox Ltd.

Finned Tubing, cont.

Tube Sizes	Surface Area Per Foot	Materials of Construction	Manufacturer
Studded tubes 1¼-6 in. o.d.	Studs: width ⅛-1¼ in. height, ⅛ in. and greater thickness as required. Of various shapes, pitched radially or longitudinally at intervals down to five per inch.	MS	Babcock & Wilcox Ltd.
0.75 in. to 8.625 in. o.d. Internal and external finning	Number of fins range from 16 to 96 dependent upon tube sizes. Fin-heights ⅛ in.-1⅛ in. Surface ratios up to 20 sq. ft per ft	CS, SS, aluminium brasses and bronzes, cupro-nickel, bimetallic. Fins homogeneously bonded to tube	Brown Fintube (Great Britain) Ltd.
1.9-6.625 in.	Studded surface up to ⅛ in. dia. Length and surface area per ft. to suit thermal design. Helical pitch layout minimum spacing 0.6 in.	CS and low chrome alloys	Birwelco Ltd.
⅛-3 in. o.d. (Also tubing with internal secondary surface for special applications, e.g. at cooling)	As required. Surface ratios up to 20:1 (Slightly less on larger sizes)	Copper and alloys, steel (mild, stainless)	Clayton Dewandre Co. Ltd.
¼-4 in.	0.81-2.78 sq. ft to 5.80-19.98 sq. ft	CS, galvanised carbon steel, aluminium finned carbon steel	G. A. Harvey & Co. (London) Ltd.
Various	Various	Ferrous, including stainless, non-ferrous	Head Wrightson Processes Ltd.

Finned Tubing, cont.

Seamless, Ta, 2 in. Ti, 5 in. Zr, 5 in. larger tubes with longitudinal and transversal seams	Various	Tantalum, Titanium Zirconium Zirconium	W. C. Heraeus Platinschmelze G.m.b.H. *Agents:* New Metals & Chemicals Ltd.
Integron tubes, wide range MF (for air-cooled heat-exchangers) 1 in bore	Area ratios up to at least 22-31	Wide range including bimetallic	Imperial Chemical Industries Ltd. Metals Division
1½ in. bore	8 fins per in. Area ratio 16-31 / 8 fins per in. Area ratio 14-20	Aluminium, fitted outer liner of steel or other material	
1½-3½ in.	Subject to design	MS hot or cold cold drawn	International Combustion Ltd.
½ to 5 in. i.d.	Ratio of finned surface area to plain up to 6:1	Aluminium and aluminium alloys	Northern Aluminium Co. Ltd.
⅝ in. o.d. tube 1.1 in. over ribbon	1.5	Non-ferrous	Serck Radiators Ltd.
⅞ in. o.d. tube 1.45 in. over ribbon	2.6	Non-ferrous or ferrous	
1 in. o.d. tube 1.7 in. over ribbon	2.9	Non-ferrous or ferrous	
⅜-3½ in. o.d.	2½-10 sq. ft	Steel or copper	Tomlinsons (Rochdale) Ltd.
1-4 in.	1.9-11.8	MS	Heat Exchange Division, Wellington Tube Works Ltd.
⅜-1½ in.	2.2-5.0	MS, alloy steel, aluminium	
2 in. o.d.	0.92 sq. ft to 3 sq. ft	CI shrunk on steel tubes	Foster Wheeler Ltd.

Refrigeration Plant

Capacity Range	Lowest Operating Temperature	Type (Ammonia absorption, etc.)	Manufacturer
13 sizes, 60 to 705 tons	40°F chilled water outlet temperature	Lithium bromide absorption	Carrier Engineering Co. Ltd.

Refrigeration Plant, cont.

Designed and supplied when part of contracts			Head Wrightson Processes Ltd.
Any size	As required	For acid concentration and similar processes	W. C. Heraeus Platinschmelze G.m.b.H. *Agents:* New Metals & Chemicals Ltd.
10,000 to 5 million Btu/hr	−40°C to −250°C	1. Ammonia absorption 2. Propane or ammonia-ethylene-methane cascade 3. Systems using low-temperature expansion turbines on air, nitrogen hydrogen or gaseous mixtures	Petrocarbon Developments Ltd.
4-500 sq. ft HTA	−50°C	Liquid coolant —e.g., Freon, liquid ammonia, brine	Powell Duffryn Carbon Products Ltd.
Any capacity to suit customers' requirements	45°F	Steam jet, water refrigeration	Worthington-Simpson Ltd.
Up to 1000 tons refrigeration	−90°F	Ammonia absorption systems	York Shipley Ltd.
1 to 300 tons refrigeration	−90°F	Ammonia-vapour compression systems	
0.05 to 500 tons refrigeration	−150°F	Halogenated hydrocarbon refrigerants—vapour compression systems	

Abbreviations: A.Bur.Ship.: American Bureau of Shipping Requirements; AOTC: Associated Offices Technical Committee—Rules for the construction, testing and scantlings of metal-arc welded steel boilers and other pressure vessels; API: American Petroleum Institution; ASME: American Society of Mechanical Engineers Boiler and Pressure Vessel Code; BS: British Standard; CI: Cast iron; CS: Carbon steel; EEUA: Engineering Equipment Users' Assoc.; HEI: Heat Exchange Institute Standards; Lloyd's Register of Shipping—Construction of boilers and other pressure vessels and testing requirements for materials; MS: Mild steel; Netherlands: Netherlands boiler code; SOD: Standard Oil Development; SS: Stainless steel; and TEMA: Standards of Tubular Exchanger Manufacturers Association. **Manufacturers' addresses:** A.E.I. Ltd., Turbine Generator Division, Trafford Park, Manchester, 17; A.P.V. Co. Ltd., The, Manor Royal, Crawley, Sussex; Alfa-Laval Co. Ltd., Great West Road, Brentford, Middx.; Ashmore, Benson, Pease & Co., Parkfield Works, Stockton-on-Tees; Babcock & Wilcox Ltd., Babcock House, 209 Euston Road, London, N.W.1; Baker Perkins Ltd., Westwood Works, Peterborough; Balfour, Henry, & Co. Ltd., Artillery House, Artillery Row, London, S.W.1; Beverley Chemical Engineering Co. Ltd., Beverley House, London Road, Horsham, Sussex; Bennett, Sons & Shears Ltd., 9 George Street, London, W.1; Birwelco Ltd., Chester Street, Aston, Birmingham, 6; Blairs Ltd., 143 Woodville Street, Glasgow, S.W.1; Brown Fintube (Gt. Britain) Ltd., Chester Street, Aston, Birmingham, 6; Buckley & Taylor Ltd., Castle Iron Works, Oldham; Burnett & Rolfe Ltd., The Esplanade, Rochester, Kent; Carrier Engineering Co. Ltd., 24 Buckingham Gate, London, S.W.1; George Clarke & North Eastern Marine (Sunderland) Ltd., Sunderland; Craig, A. F., & Co. Ltd., Caledonia Engineering Works, Paisley, Renfrew; Dore, John, & Co. Ltd., 31 Bromley High Street, Bow, London, E.3; Foster Wheeler Ltd., Foster Wheeler House, 3 Ixworth Place, London, S.W.3; Fraser & Fraser Ltd., St. Leonards Street, Bromley-by-Bow, London, E.3.; Fraser, W. J., & Co. Ltd., Harold Hill, Romford, Essex; Giusti, T., & Son Ltd., 210 York Way, London, N.7; Grazebrook, M. & W, Ltd., Dudley, Worcs.; Harvey, G. A., & Co. (London) Ltd., Greenwich Metal Works, London, S.E.7; Head, Wrightson & Co. Ltd., Teesdale Ironworks, Thornaby-on-Tees; Heat Transfer Ltd., 30 Church Street, Croydon; Horseley Bridge & Thomas Piggott Ltd., Tipton, Staffs.; Holden & Brooke Ltd., Sirius Works, Manchester, 12; Holmes, W. C., & Co. Ltd., P.O. Box B7, Turnbridge, Huddersfield; Hygrotherm Engineering, The, 5 Fitzhardinge Street, London, W.1; Imperial Chemical Industries Ltd., Kynoch Works, Witton, Birmingham, 6; International Combustion Ltd., 19 Woburn Place, London, W.C.1; Jenkins, Robert, & Co. Ltd., Rotherham; Johnson (London), A., Ltd., Dukes Road, London, W.3; Kellogg International Corp., Kellogg House, 7 Chandos Street, London, W.1; Kestner Evaporator & Engineering Co. Ltd., 5 Grosvenor Gardens, London, S.W.1; Mainwaring, Henry (Coppersmiths), Ltd., 2 Eastvale Place, Glasgow, C.3; Marston Excelsior Ltd., Wobaston Road, Fordhouses, Wolverhampton; Metal Propellers Ltd., 74 Purley Way, Croydon; New Metals & Chemicals Ltd., Chancery House, Chancery Lane, London, W.C.2; Newton Chambers Ltd., Thorncliffe, near Sheffield; Nordac Ltd., Uxbridge, Middx.; Petrocarbon Developments Ltd., 17 Stratton Street, London, W.1; Powell Duffryn Carbon Products Ltd., Springfield Road, Hayes, Middx.; Power-Gas Corporation Ltd., The, Parkfield Works, Stockton-on-Tees; Q.V.F. Ltd., Duke Street, Fenton, Stoke-on-Trent, Staffs.; Rose, Downs & Thompson Ltd., Old Foundry, Hull; Serck Radiators Ltd., Warwick Road, Greet, Birmingham, 11; Simmons & Hawker Ltd., Southdown Works, Point Pleasant, Wandsworth, London, S.W.18; Simon-Carves Ltd., Cheadle Heath, Stockport; Smith (Engineers), Leonard, Ltd., Abford House, Wilton Road, London, S.W.1; Spirax-Sarco Ltd., Charlton House, Cheltenham, Glos.; Stainless-Steel Vessels (London) Ltd., 4 Manorgate Road, Kingston-on-Thames, Surrey; Sturtevant Engineering Co. Ltd., Southern House, Cannon Street, London, E.C.4; Taylor Rustless Fittings Co. Ltd., The, Ring Road, Lower Wortley, Leeds, 12; Thompson Bros. (Bilston) Ltd., Bradley Engineering Works, Bilston, Staffs.; Thompson, John, Ltd., Wolverhampton, Staffs.; Weir, G. & J., Ltd., Cathcart, Glasgow, S.4.; WellingtonTube Works Ltd., Great Bridge, Tipton, Staffs.; White's of Hebburn (Engineers) Ltd., 49 Leadenhall Street, London, E.C.3; Whessoe Ltd., 25 Victoria Street, London, S.W.1; Worthington-Simpson Ltd., Queen's House, Kingsway, London, W.C.2.

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SIMULTANEOUS HEAT AND MASS TRANSFER IN COOLING TOWERS—PART I

Experimental work is described which shows that the liquid-film resistance to heat transfer is not negligible

by W. J. Thomas, B.Sc., Ph.D. (Chem. Eng.), F.R.I.C., A.M.I.Chem.E., M.Inst.F., Dip.Chem.Eng., and P. Houston B.Sc., Ph.D. (Chem. Eng.), A.R.I.C.*

MANY attempts have been made to establish the conditions of simultaneous heat and mass transfer in cooling towers. ROBINSON[1] and WALKER, LEWIS and MCADAMS[2] based their studies on the WHITMAN two-film theory. The results of this work and that of LEWIS,[3] who established the ratio of the heat- and mass-transfer coefficients, were used by MERKEL[4] to derive the equation:

$$\int_{H_1}^{H_2} \frac{dH}{H_1 - H} = \frac{k_G a \,.\, M_G \,.\, P \,.\, Z}{G'_G} \qquad \ldots.(1)$$

The most common method of solving problems is a simplification of this equation. The interfacial condition is difficult to establish, and an assumption of no resistance to heat transfer in the liquid film allows the use of an "overall coefficient" as in the equation

$$\int_{H_1}^{H_2} \frac{dH}{H' - H} = \frac{K_G a \,.\, M_G \,.\, P \,.\, Z}{G'_G} \qquad \ldots.(2)$$

The existing evidence is so conflicting (Table 1) that it is rather unwise to neglect the liquid-film, heat-transfer resistance. MCADAMS[5] devised a method of allowing for this resistance and for determining H_i. The method is based on the relationship

$$\frac{-h_L a}{k_G a \,.\, M_G \,.\, P} = \frac{H_i - H}{t_i - t} \qquad \ldots.(3)$$

The line representing the operating conditions in a tower and the saturation curve are drawn on an enthalpy-temperature diagram (Fig. 1). Corresponding operating and interfacial conditions are then given by the extremities of parallel tie-lines having a slope of $\frac{-h_L a}{k_G a \,.\, M_G \,.\, P}$. The value of the integral $\int \frac{dH}{H_i - H}$ is found graphically from a plot of H v $\frac{1}{H_i - H}$ between the limits of H_1 and H_2. The method depends upon a proper choice of tie-line slope, i.e., on the values of $h_L a$ and $k_G a$. Literature is so diverse on the values of these coefficients that the method is difficult of application.

It is doubtful if much value can be placed on $k_G a$ determined on the basis of absence of liquid-film resistance to heat transfer.

Mickley Method

A method proposed by MICKLEY,[6] which is an extension of the work of MERKEL[4] and MCADAMS[5] attempts to overcome the difficulty of establishing the individual values of $h_L a$ and $k_G a$ for solution of a tower design. The ratio $h_L a / k_G a$, the "tie-line" slope, is found by successive approximation.

A value of the tie-line slope is chosen and assumed to be constant throughout the tower. A series of tie-lines having this slope can then be drawn to give the interfacial condition corresponding to any operating condition.

MICKLEY showed that:

$$\frac{dH}{t_G} = \frac{H_i - H}{t_i - t_G} \qquad \ldots.(4)$$

This equation reflects the changing condition of the air as it passes through the tower. Using Equations (3) and (4) and the chosen tie-line slope, an air condition curve can be constructed (Fig. 1). The initial condition of the

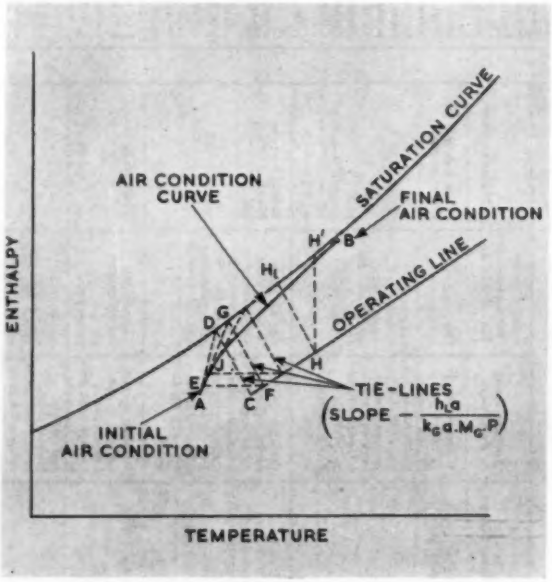

Fig. 1. Humidity diagram with air-condition curve, AB.

Dr. Thomas *is Reader in Chemical Engineering at Battersea College of Technology.* **Dr. Houston** *is on the chemical engineering staff of Peter Spence Ltd., Widnes.*

* *Paper on work presented for a Ph.D. degree of the University of London.*

Symbols Used

a = interfacial contact area per unit volume of packing (ft²/ft³);
G_L = liquid rate (lb./ft² tower c.s.a/hr);
G'_G = dry air rate (lb. dry air per hour in water vapour mixture/ft² tower c.s.a);
H = enthalpy of the air-water vapour mixture (Btu/lb. dry air);
H' = enthalpy of saturated air at temperature t' of the main water stream (Btu/lb.);
h_G = gas film heat-transfer coefficient;
h_L = liquid film heat-transfer coefficient;
K_G = overall coefficient of mass transfer (lb. mol/hr ft² atm);
k_G = gas phase mass-transfer coefficient (lb. mol/hr ft² atm);
M_G = molecular weight of air;
N_G = number of transfer units;
P = total pressure of the system, i.e., atmospheric pressure;
S_{av} = average humid heat of air-water vapour mixture (Btu/lb. °F);
t = bulk temperature of air-water vapour mixture (°F);
t_G = dry bulk temperature of air-water vapour mixture (°F);
t' = bulk temperature of liquid water (°F);
W = water content of air-water vapour mixture (lb./lb. dry air);
Z = packed height (ft); and
λ = latent heat of vaporisation (Btu/lb.).

Subscripts

G refers to gas phase;
i „ „ interfacial conditions;
L „ „ liquid phase;
1 „ „ the top of the tower; and
2 „ „ the bottom of the tower.

air is given by A and the final condition by B. The operating condition at the bottom of the tower is at C. The corresponding interfacial condition is at D, the end of a tie-line through C. The line AD has a slope defined by

TABLE 1

Literature Survey	*References*
Relationship between gas film heat and mass-transfer coefficients	
(i) Derivation and values given	1, 2, 7, 8, 9, 10, 11
(ii) Effect of spray—high values of humid heat Lewis relationship questioned—not constant or equal to humid heat of main air stream	12, 13, 14
(iii) Allowance made for deviation of LEWIS's relationship from unity for water	15
Significance of liquid-film resistance to heat transfer	
(iv) Liquid film resistance far from negligible	16, 17, 18, 28
Characteristics of tower packings and influence of water and air flow rates on coefficients	
(v) Wetting of grid packings	19, 20, 21, 22, 23, 26
(vi) Effect of flow rates on overall coefficient	
(a) 16 ft² cross-flue tower—no correlation by an equation of form $K_Ga = \alpha G_L^{\beta} G'_G{}^{\gamma}$	23
(b) 36 ft² grid tower $K_Ga = \alpha G_L^{0.4} G'_G{}^{0.5}$	24, 26
(c) 76 ft² tower—ovate slats— K_Ga practically independent of water rate provided packing is fully wetted	13
(d) K_Ga proportional to $G'_G{}^{0.4}$	25
(e) Spray-filled tower—large quantity of water as a film on the wall $K_Ga = \alpha G_L^{0.3} G'_G{}^{0.5}$ wall $K_Ga = \alpha G_L$ spray Combined spray and wall $K_Ga = \alpha G_L^{0.76} G'_G{}^{0.17}$	12
(f) Effect of maldistribution of water	21, 27

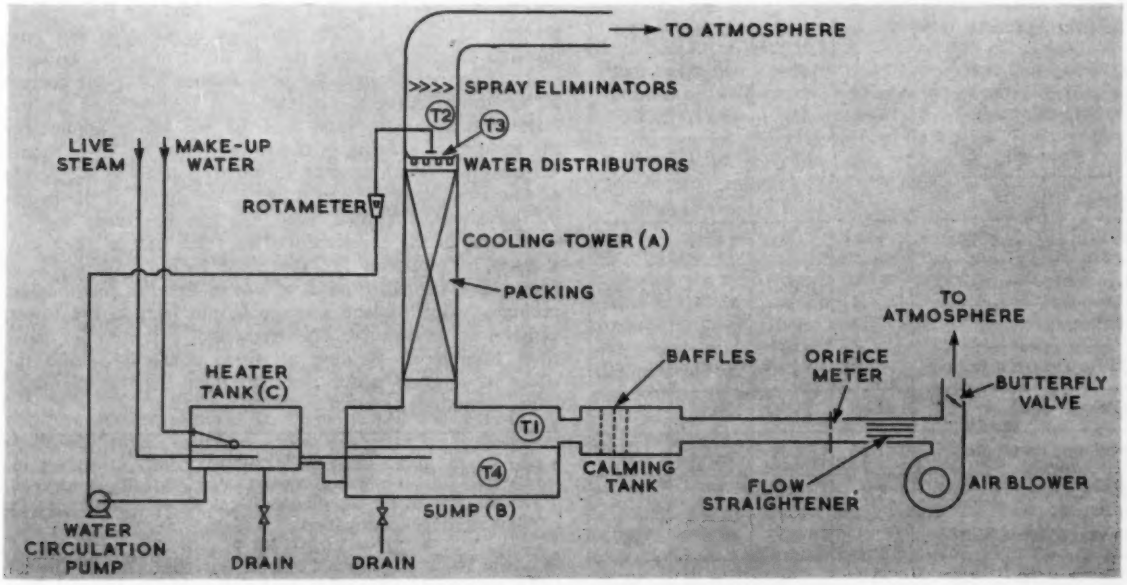

Fig. 2. Diagram of experimental cooling-tower rig.

TABLE 2—Temperature Measurement

Stream	*Position*	*Frequency of Readings*	*Remarks*
Inlet Air	Main air stream in sump tank. (1) Fig. 2	One reading before and after each 30-min. run	Mercury in glass thermometer shielded from the spray and each other. Air temperature varies little over a day. Wet and dry bulb temperatures.
Exit Air	Air immediately above distributors. (2) Fig. 2	Every 5 minutes	Mercury in glass thermometer shielded from spray. Care taken to ensure air thoroughly mixed at this point. Wet and dry bulb temperatures.
Inlet Water	Water in primary trough. (3) Fig. 2	Continuously	Mercury in glass thermometer.
Exit Water	Water in sump tank. Fig. 2	Continuously	Two mercury in steel bulbs connected to a Bristol Recorder. Bulbs immersed $\frac{1}{4}$-$\frac{3}{4}$ in. below surface of water.

TABLE 3

Packed Height	3$\frac{3}{8}$in. or Three Packing Elements			
Experiment No.	PP1	PP2	PP3	PP4
Water rate (lb./hr ft²)	2000	1500	1260	1000
Air rate (lb./hr ft²)	880	880	880	880
Inlet air (°F), w.b.	64.4	64.0	63.1	62.6
Temperatures, d.b.	74.1	74.3	73.9	73.8
Outlet air (°F), w.b.	84.2	82.9	81.7	80.5
Temperatures, d.b.	85.8	84.7	83.7	82.9
Inlet water temp. (°F)	110.0	110.0	109.0	110.2
Outlet water temp. (°F)	102.1	100.0	98.8	96.7
Heat lost by water (Btu/hr)	15,800	15,000	13,986	13,500
Heat gained by air (Btu/hr)	15,894	14,635	14,033	13,352
Difference	94	365	47	148
% Error in heat balance	−0.59	+2.49	−0.33	+1.09
†Enthalpy inlet air	21.88	21.56	20.91	20.51
†Enthalpy outlet air	41.20	39.34	37.98	36.67
*Dry air rate	871	871	871	872
Average humid heat	0.2482	0.2478	0.2475	0.2471
Tie-line slope	−1.16	−1.08	−1.03	−0.98
Number transfer units (uncorrected)	1.090	1.046	1.023	0.998

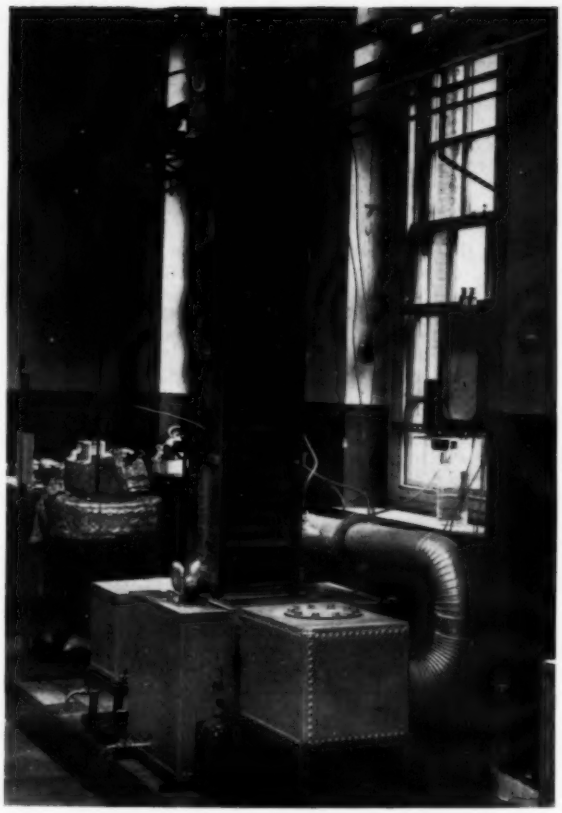

Fig. 3. A view of the tower showing criss-cross slat packings.

Equation (4) and gives the rate of change of air condition. This would only apply over a small increment of change, as initial air condition changes rapidly. If a small increment is chosen the condition of the air at the end of the increment is E. The corresponding operating condition is F. A tie-line from F, i.e., FG establishes the new interfacial condition and EG represents the new rate of change of air condition over a small increment, say to J. The procedure is repeated until the final air condition is reached at B. If the air condition curve does not pass through B, then another tie-line slope must be assumed and the procedure repeated until it does. Once the correct air condition curve is established, it follows that the tie-line slope chosen to yield it is the one which applies for the conditions existing in the tower. Thus h_L/k_G is found.

Equation (1) can now be solved to determine the height of tower required for any duty. Alternatively, if the height of the tower is known, then $k_G a$ can be found for the conditions of the experiment. This value of $k_G a$ when substituted in Equation (3), the slope being known, $h_L a$ is found. Further substitution of $k_G a$ in LEWIS's relationship, taking a value for the average humid heat in the tower, yields a value for $h_G a$. The method of MICKLEY is, therefore, capable of yielding all three coefficients, and the effect of air and water rates on them can be examined experimentally.

---

* Dry air rate $= \dfrac{\text{Nominal air rate (lb/ft}^2\text{)}}{1 + \text{Water content moist air (lb./lb. dry air)}}$

† The enthalpy of the air streams is calculated according to the following simplified equation:

$$H = S\,(t_G - 32) + \lambda_{32}\,W.$$

where S = average humid heat in the system (Btu/lb. dry air, °F);
t_G = dry bulb temperature of air stream (°F);
λ^{32} = latent heat of vaporisation of water at the air datum temperature 32°F (λ_{32} = 1075.2 Btu/lb.); and
W = water content of the air stream (lb./lb. dry air).

TABLE 4

Packed Height	10½ in. or 10 Packing Elements in All Cases							
Experiment No.	EE1	EE2	EE3	EE4	EE1r	EE2r	EE3r	EE4r
Water rate (lb./hr ft²)	2000	1500	1260	1000	2000	1500	1260	1000
Air rate (lb./hr ft²)	1680	1680	1680	1680	1680	1680	1680	1680
Inlet Air (°F) Temp. wet bulb	65.3	65.1	65.5	65.5	68.2	68.2	68.3	68.4
Inlet Air (°F) Temp. dry bulb	70.0	70.9	71.4	72.1	79.6	79.2	79.8	80.0
Outlet Air (°F) Temp. wet bulb	86.0	84.9	83.95	82.6	89.2	86.85	85.45	83.6
Outlet Air (°F) Temp. dry bulb	86.0	84.9	84.1	83.0	90.4	88.5	87.45	86.3
Inlet water temp. (°F)	109.8	109.4	109.5	110.0	110.1	110.0	110.2	110.8
Outlet water temp. (°F)	93.2	89.1	87.3	84.8	92.0	89.7	88.5	86.6
Heat lost by water (Btu/hr)	33,200	30,450	27,972	25,200	36,200	31,050	37,342	24,200
Heat gained by air (Btu/hr)	32,257	30,490	28,319	25,428	35,231	30,401	27,565	24,258
Difference	943	40	347	228	969	649	223	58
% Error in heat balance	+2.92	−0.13	−1.22	−0.90	+2.75	+2.13	−0.81	−0.24
Enthalpy inlet air	22.63	22.34	22.69	22.76	24.84	24.83	24.89	25.04
Enthalpy outlet air	43.01	41.57	40.51	38.76	47.16	44.09	42.32	40.37
Dry air rate	1659	1660	1660	1660	1660	1660	1660	1660
Average humid heat	0.2489	0.2484	0.2489	0.2482	0.2495	0.2490	0.2487	0.2484
Tie-line slope	Mickley Method		−1.38	−1.30	−1.58	−1.47	−1.39	−1.33
Number transfer units (uncorrected)	Does not work		1.258	1.149	1.496	1.353	1.261	1.154

Apparatus and Experimental Procedure

The apparatus is shown in Figs. 2 and 3. The cooling tower consisted of a 6-ft high by 12 in. sq. cross-section square box, three sides of which were wood and the other perspex. The tower was packed with wooden slats in grid form to give a cross-flue effect. The water distribution system comprised one primary trough at right angles to, and feeding, three secondary troughs. Water overflows from the latter in 66 separate streams. A complete description is given elsewhere.[28]

The experimental procedure is to adjust conditions until the inlet water temperature is constant at 110 ± 2°F. Approximately 20 minutes are required to stabilise the condition, and experimental readings are taken over a period of 30 minutes. The times and places at which temperatures are taken are given in Table 2.

Selection of Operating Variable Levels

The three major operating variables are: water rate; air rate; and packed height. Controlled variation in operating level was confined to these three. The inlet water temperature was maintained constant at 110°F ± 2°F in all cases, any slight variation about the mean being assumed insignificant. The mean air temperature was, in all cases, that of the ambient atmosphere. The operating levels selected for the major variables were as follows:

1. Air Rate: 1680, 1260, 1040, 865 lb./hr ft² tower cross-section. These four levels cover the range leading up to the rates at which excessive spray carry-over from the top of the packing is caused.

2. Water Rate: 2000, 1500, 1260, 1000 lb./hr ft² tower cross-section. These levels cover the most interesting range, namely that around the mean effective liquid rate (*ca.* 1300 lb./hr ft² for the packing used).[21, 22]

3. Packed Height: 1ft 1½ in. 10½ in. 6¼ in. 3¾ in. 1¼ in.
Packing Elements: 12 9 6 3 1

These packed heights are much lower than those normally used, but result from the necessity to operate with the outlet air in an unsaturated condition. Preliminary experiments carried out in the same apparatus but with much larger packed height (*ca.* 4 ft) resulted in cases where the outlet air was saturated. MICKLEY'S method does not apply here.

The experiments were carried out for all combinations of each variable. The runs for the lowest packed height were completely duplicated. Total number of experiments, including the replicates for the lowest packed height, was 96. When altering the height of packing, the distance of the bottom slat above the surface of the water in the sump was kept constant. In this way the magnitude of the end effect, due to spray and air interaction, was reproduced in successive experiments.

Experimental Results

The complete experimental block of results were obtained from 96 runs.[28] Tables 3 and 4 are representative only. Table 3 shows the case where MICKLEY'S method can be applied. The results are obtained using a low packed height and low air rate. Table 4 is for high packed height and high air rates, and in this case MICKLEY'S method does not work due to saturation of the exit air.

ADVANCES IN BOILING HEAT TRANSFER

A summary of recent useful correlations for pool and nucleate boiling heat transfer based upon research and plant observations

A METHOD has been reported by FORSTER and GREIF[1] for predicting heat flux in boiling liquids with forced convection and sub-cooling. The aim of this work was to relate the heat flux to such fundamental properties of the boiling liquid as temperature, pressure, superheat, convective velocity, heat of vaporisation and thermal conductivity. The condition of the surface and its diameter were not considered to be of prime importance in the boiling process. Among the mechanisms of nucleate boiling considered in the paper were: (1) micro-convection in a laminar sub-layer; (2) bubbles contribute a species of surface roughness; (3) latent-heat transport by bubbles; and (4) vapour liquid exchange action. Of these, (4) accounts for observed heat flux in this type of boiling. The assumption that the action of bubbles is to increase the heat flux by causing strong micro-convection in a highly superheated sub-layer conflicts with the experimental finding that the heat flux is insensitive to the level of sub-cooling. The action of mechanism (4), which assumes heat to be transferred by the vapour-liquid exchange taking place every time a bubble grows and then collapses upon, or detaches itself from the heating surface, is by itself sufficient to account for nucleate boiling heat transfer.

The heat flux correlation presented is:

$$q = 4.3 \times 10^{-8} \frac{ac\rho_L T_S}{\sigma^{\frac{1}{2}}(\lambda\rho_V)^{\frac{5}{2}}} (c\,T_S\sqrt{a})^{\frac{1}{2}} \left(\frac{\rho_L}{\mu}\right)^{\frac{5}{8}} \left(\frac{\mu\,c}{k}\right)^{\frac{1}{2}} \triangle P^2 \quad \ldots.(1)$$

The equation was tested with experimental data for the following liquids and physical conditions:

water	for pressures from	1-50 atma
n-butyl alcohol	at	50 psia
aniline	at	35 psia
mercury	at	1-3 atma

It also gave fair agreement with published experimental work on boiling sodium.

The use of this equation to calculate the heat flux in a sub-cooled liquid with forced convection is illustrated. A heat flux is first calculated as the intersection of this equation with the SIEDER-TATE equation. From the relation $q_i = 1.4q_0$ derived by the authors of this paper, the value of T_i, the heating surface temperature at the point where the transition from convection-pool-boiling is complete, is then found directly from (1). With T_i known, three regimes are possible. If $T_w > T_i$, then Equation (1) will apply. For $T_w \leqslant T_i$ the SIEDER-TATE equation applies. For the narrowest range between incipient boiling and T_i the heat flux can be estimated by assuming a linear increase between the point of incipient boiling and T_i. It is thus possible to predict the heat flux in a moving, sub-cooled liquid for the entire temperature range below the maximum or peak heat flux in nucleate boiling.

KOVALENKO[2] investigated the effects of vibrations upon heat transfer under boiling conditions. In his experiments

Symbols Used

A = surface area on boiling side, ft;
B = a coefficient in LEVY'S correlation;
D = tube diameter, ft;
F = fraction of surface covered by accumulated condensate;
G = mass flow rate, lb./hr ft^2;
L = tube length, ft;
H = ratio of segment height to tube diameter;
Nu = Nusselt Number $\frac{h_i D}{k}$;
Pr = Prandtl Number $\frac{c\mu}{k}$;
P = pressure, lb./ft^2 abs.;
Q = quantity of liquid;
Re_s = Reynolds Number (pseudo) $DV_s\rho/\mu$;
$\triangle T$ = temperature difference, $T_i = T_w - T_s$;
T = temperature;
$\triangle P$ = pressure difference corresponding to superheat, T_i, lb./ft^2;
U_{obs} = observed overall coefficient, Btu/hr ft^2 °F;
W = fluid rate, lb./hr;
V = vapour velocity, ft/hr;
a = thermal diffusivity, ft^2/hr, an exponent;
b = an exponent;
c = specific heat, Btu/lb. °F;
e = an exponent;
h = film coefficient for heat transfer, Btu/hr ft^2 °F;
k = thermal conductivity, Btu/hr ft^2 °F/ft;
q = heat flux, Btu/hr ft^2;
λ = latent heat of evaporation, Btu/lb.;
μ = viscosity, lb./hr ft;
ρ = density, lb./cu. ft; and
σ = surface tension, lb./ft.

Subscripts

i = tube interior;
L = liquid;
S = saturation;
V = vapour; and
w = wall or heating surface.

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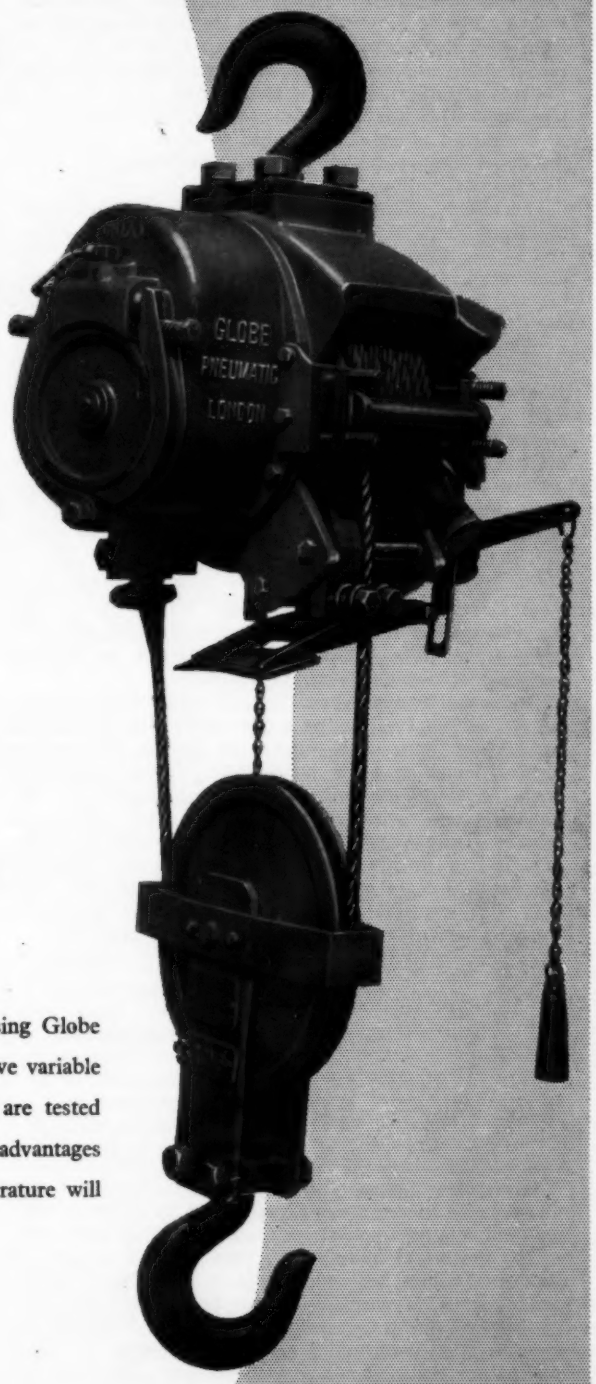

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he used a red copper tube of ½ m. length and 38-mm bore heated by a nichrome spiral mounted inside the tube. The tube was subjected to vibrations generated mechanically with a range of 700-3000 per min. for heat fluxes varying from 8000-25,000 kcal/m.² hr. Compared with a static surface in the region of low flux, vibrations slightly increased the rate of heat transfer. At greater heat fluxes the heat-transfer rate decreased. In the range 6000-15,000 kcal/m.² hr the rate diminished, but began to increase again near the upper limit, although at this point it was still lower than the static tube flux.

The author concludes that the vibrations induced turbulence in the layers of water adjacent to the actual surface and at low fluxes thereby increased the heat transfer. For moderate heat fluxes, e.g. >6000 kcal/m.² hr, the vibrating motion leads to premature breakaway of the bubbles, thereby reducing the turbulising effect upon the layers of liquid around the tube wall. At high fluxes the rate of steam formation is so great that the negative effect of vibration decreases progressively with increase in heat flux.

Another equation for boiling-heat transfer, applicable to nucleate boiling conditions, was based upon the bubble growth rate close to a heated surface and an empirical determination of the relation between heat transfer at the heated surface and that at the bubble surface. The equation proposed by LEVY[3]

$$q = \frac{k\,c\,\rho_L^2}{\sigma\,T_S\,(\rho_L - \rho_V)}\,\frac{1}{B_L}\,(\triangle T)^3 \qquad \ldots\ldots(2)$$

where B_L is a coefficient, determined empirically, correlates all fluids independently of pressure and heating surface-fluid combinations.

This equation requires the use of a dimensionless correlation coefficient (given by the author's Fig. 4) derived from observations on a number of systems and heating surfaces including water at 14.7-2465 psia for a heat-flux range of 10^4-10^7 Btu/hr ft² on platinum. Values of this coefficient are given below. Benzene and ethanol at pressures from 14.7-515 psia and heat fluxes of the order of 8.10^3-2.10^5 Btu/hr ft² are also representative of the test conditions used to obtain values of this coefficient. The data upon which this correlation is based are thus more extensive than those underlying FORSTER'S correlation.

$\rho_V\lambda$	400	200	150	100	80	60	20
$\frac{1}{B_L} \times 10^{-6}$	320	130	90	68	55	45	32
$\rho_V\lambda$	2000	1000	600				
$\frac{1}{B_L} \times 10^{-6}$	1900	1025	570				

The shortage of published work on actual plant performance of heat exchangers was noted by GILMOUR[4] who reported data on a number of vaporisers. These latter were of the horizontal hairpin tube type fitted in vertical or horizontal kettles, with one exception, which had two serpentine coils in parallel for the heating element. The heating medium in each case was steam condensing inside the tubes with pool boiling taking place outside the tubes. The liquids boiled included 18% aqueous acetic acid. He compares the theoretical overall coefficients with those actually obtained, and finds that there is a considerable discrepancy between the two sets of results. After seeking the cause of the discrepancy, GILMOUR came to the following conclusions:

(1) the tubes were not fouled;

(2) the Nusselt equation for condensing vapour will give high results for steam condensing inside horizontal tubes, unless allowance is made for the reduction of effective area by the presence of condensate. The effective area may be estimated by the equation of GREVE:

$$Q = 9.43\ D^{2.56}\ H^{1.94}$$

which relates the flow of condensate to its depth and bore of tubing. The effective area is assumed to be a function of the fraction of area unflooded at the exit. The true observed overall resistance would then be $(1 - F)^a / U_{obs}$ where $a = 0.648$; and

(3) for the boiling-film resistance the GILMOUR correlation $\left(\frac{h}{c\,G}\right) Pr^{0.4} \left(\frac{\rho_L\,\sigma}{P^2}\right)^{0.425} = 0.001\ Re^{0.3}$ can be used, provided it is corrected by two factors N_{BV}^{-b} and V^{-e}

where N_{BV} = average number of superimposed tubes in a vertical row;
V = superficial vapour velocity >1 ft/sec.;
$b = 0.185$; and
$e = 0.358$.

The Reynolds Number in this work is given by

$$\frac{W}{A}\,\frac{\rho_L}{\rho_V}.$$

Good practice in the arrangement of the heating surface of a horizontal vaporiser tube bundle avoids overlap of tubes in adjacent vertical rows. Square pitch rotated 45 degrees meets this requirement satisfactorily. When scale-up from one plant scale vaporiser to a larger size is to be undertaken, it is inadvisable to proceed unless the observed performance can be interpreted theoretically. GILMOUR[4] readily admits that his method of handling plant data is akin to "second guessing"; but he claims that it helps to establish the applicability of heat-transfer theory to the design of full-scale equipment. This claim has some considerable weight behind it, since, in addition to the four plant examples quoted, a further forty were available which verified his conclusions.

Another practical study was carried out by KEVILLE,[5] who investigated heat transfer in a falling-film evaporator. Although the work described was confined to the concentration of milk, the calculations derived should be capable of predicting the performance for other fluids besides whole-milk. The data were obtained from an evaporator with ten 10 ft long 3 m. o.d. stainless-steel tubes and the the boiling temperatures obtained by varying the pressure ranged from 50°F to 150°F.

The equations obtained for correlating the boiling heat-transfer coefficients and equipment geometry are:

$$Nu = 5.40 \times 10^{-4}\ Re^{0.5}\ Pr^{0.3} \left(\frac{PL}{\sigma}\right)^{0.9} \quad \text{for Re} > 7000$$

and

$$Nu = 1.98 \times 10^{-5}\ Re^{0.35}\ Pr^{0.3} \left(\frac{PL}{\sigma}\right)^{0.9} \quad \text{where Re} < 7000$$

Since the velocity of the liquid flowing down the inner walls could not be measured directly, it was assumed that the most important factors determining it were vapour velocity and liquid density and viscosity. In the Reynolds Number appearing in these equations the value of velocity term is the exit vapour velocity ÷ 2. One of the weaknesses of these correlations, recognised by their author, is that they are based on a unique tube diameter and length. Consequently, these variables are to be investigated and a further paper is to be published on the results obtained.

REFERENCES

[1] Forster, K. E., and Greif, R. Joint A.S.M.E.-A.I.Ch.E. Heat Transfer Conference, Chicago, August, 1958. Paper No. 58-HT-U.
[2] Kovalenko, V. F. *Teploenergetika*, 1958, **2**, 76-79.
[3] Levy, S. Joint A.S.M.E.-A.I.Ch.E. Heat Transfer Conference, Chicago, August, 1958, Paper No. 58-HT-8.
[4] Gilmour, C. H. Paper presented to Joint A.S.M.E.-A.I.Ch.E. Heat Transfer Conference, Chicago. August, 1958.
[5] Keville, J. F. Paper presented to Joint A.S.M.E.-A.I.Ch.E. Heat Transfer Conference, Chicago, August, 1958.

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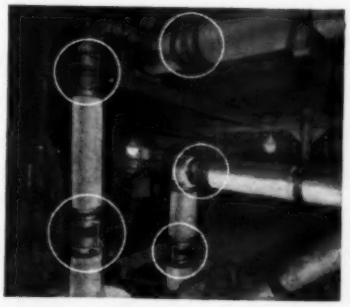

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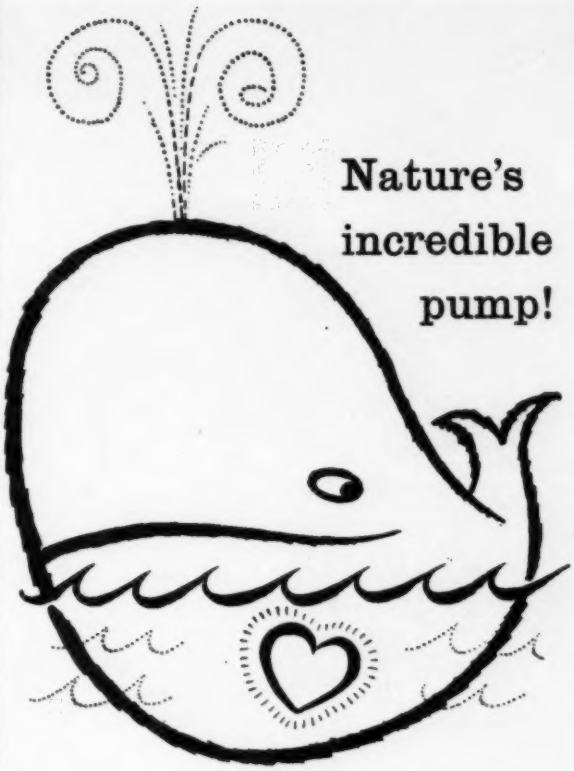

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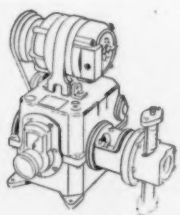

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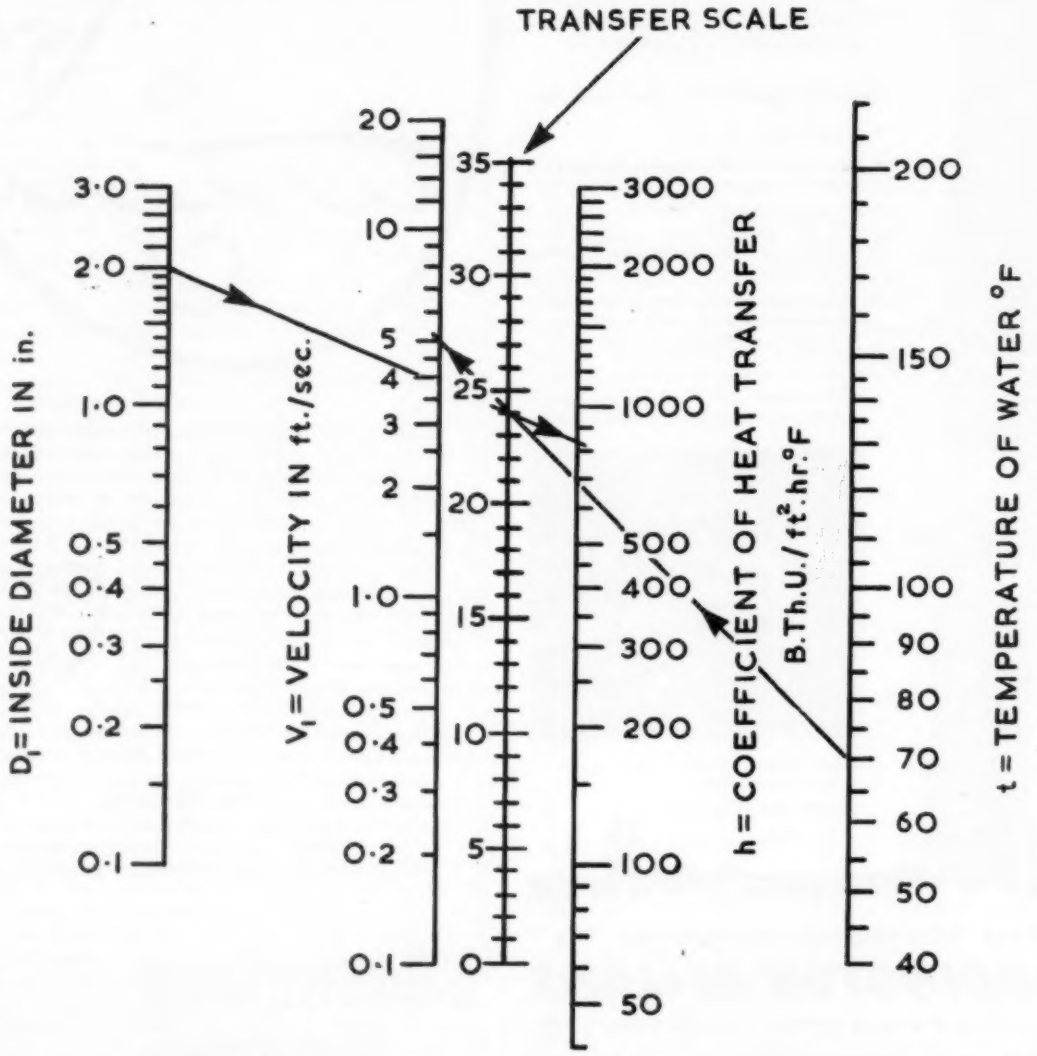

* McAdams, W. H. "Heat Transmission", second edition, p. 183, for water inside tubes over the temperature range 40 to 220°F, based on a density of 62.3 lb./cu. ft.

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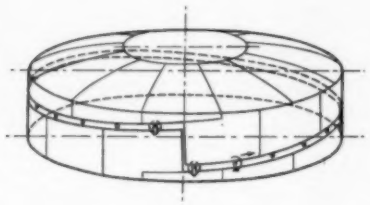
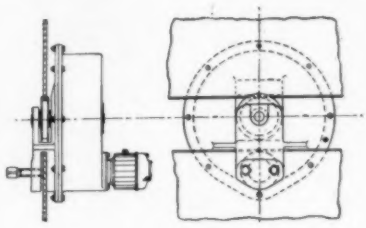
Assembling Vertical Tanks





THE CONVENTIONAL METHODS of assembling storage tanks have disadvantages overcome by this new method. The floor and domed roof are prepared in the usual way, but the manner of preparing the cylindrical wall is the major point of departure from existing practice. The sheets which are to form the wall of the tank are so cut that their upper and lower edges form a spiral instead of a closed circle; the sheets of the wall are coiled so as to allow them to ascend the spiral. After the top sheet-coil of the future tank has been set into the position and connected with the arched roof, the upper part of the tank starts rotating around the vertical axis by means of an electrically-driven pulley device, and is at the same time lifted upward until a space is left for the insertion of another sheet of material. The succeeding sheets are inserted and welded in the same way, and once the tank reaches its final height its construction is finished quite readily.

This method of assembling vertical tanks has a number of advantages. In the first place, the work of arranging the sheets around the structure is not required. The sheets are inserted and welded at one place, and an automatic welding machine can be used. All the welds can be done with a single automatic machine from one position. Through improvement in the quality of the welded joints it is possible to decrease the wall thickness so much that the weight of the tanks can be reduced by as much as 30%. The assembly of tanks of normal height can be carried out without scaffolding, and since the operation has a mass-production character it can be speeded up by using a double-threaded spiral. This provides two working zones, and the speed of erection doubles.

The diagrams illustrate the method. The spiral is formed by the sheets, the upper edges forming one thread of the spiral. The pulley device for positioning the sheets is shown in the second diagram.

V. MACKU

Reducing Corrosion Caused by Boiler Feed Water

CONSIDERABLE TROUBLE has been experienced at Kurnell, Australia, in a boiler feed-water system. The municipal water becomes saturated with oxygen as it enters the break tank, which equipment is prescribed by law. After zeolite softening, the boiler feed-water is preheated by exchange with blow-down and vented gases. The increase in temperature accelerates corrosion. After a survey, experimental work was carried out with several corrosion inhibitors and combinations of inhibitors. The most effective, in economical dosages, was found to be the addition of 4 ppm zinc chromate and 5 ppm sodium hexametaphosphate. A marked synergistic effect was apparent. The treatment is especially applicable to boiler feed-water treatment because no gases are evolved to contaminate the steam. No scale formation is caused by these dosages and tertiary phosphate treatment can be eliminated.

The references given are pertinent:

Indelli, A. "Sodium Polyphosphates as Inhibitors", *Metallurgia Italiana*, May, 1957, **49**, 331-36.

"Passivation of Iron by Chromate", *Nature*, 1957, **4574**, 27-29.

"Activation and Inhibition of Corrosion by Metallic Cations", *Corrosion*, July, 1958, 38.

"Polyphosphates and Metallic Cations as Inhibitors", *Werkstoffe und Korrosion*, January, 1958, 379-83.

"Calgon", U.S.P. 2,337,856.

K.G.G.

Sugar Filtration

THE INTRODUCTION of nylon has led to significant reductions in operating costs in factories producing sugar from beet. In many instances the annual cost of top cloths (jute is normally used for the undercloth) has been cut by half.

Sugar is produced by slicing the beet into thin cossettes which are treated with hot water to extract the sweet juices. The liquid is then purified and boiled to dispose of the water. It is in the purification processes that nylon plays its part.

The first stage is to add milk of lime to the raw juice and treat it with carbon dioxide. This precipitates many impurities and enables them to be filtered out. After a second carbonation, with or without the addition of lime, the juice is again filtered. It is then treated with sulphur dioxide and filtered for the third and last time.

Filtration is carried out at temperatures of approximately 90°C with a *p*H factor varying between 11.0 and 7.0. The conventional fabric is the 15-oz. cotton, but experiments showed that a nylon fabric needed to be heavier than this. The fabric now used extensively for all three filtrations is 18 oz. and consists of nylon staple fibre doubled with continuous fila-

ment nylon. The price is slightly more than four times as much as that of 15-oz. cotton.

As the life of a cotton cloth on the first carbonation plate-and-frame presses averages about 30 days, a nylon cloth must last longer than an average campaign's run (110-115 days). At several factories which have been using nylon for some time past it has been found that a life of at least two campaigns can be expected.

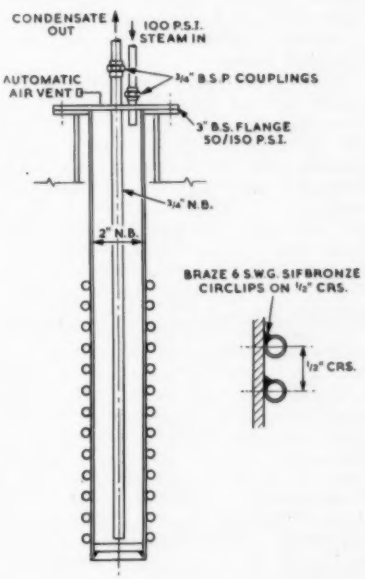
Considerable economies have also been achieved by using nylon on the second carbonation presses. As the cause of breakdown of cloths on the first presses is usually mechanical damage at the edges of the frames, factories employing smaller second presses are able to use cut-down cloths from the first presses.

To obtain the best from the nylon cloths it is necessary to wash them every five to seven days. If they show signs of becoming hard this is overcome by dipping in a 5% hydrochloric acid solution and neutralising in a 5% sodium carbonate solution before washing.

Shrinkage problems are reduced to negligible proportions by avoiding drying the cloths during a campaign. At the end of a campaign cloths are returned wet to the presses and allowed to dry out slowly. As nylon cannot rot, this procedure is perfectly safe. A new cloth tried out last season is so resistant to shrinkage that even these precautions are unnecessary.

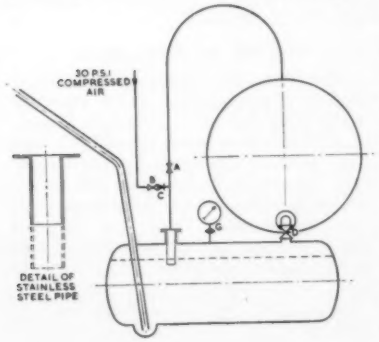
Inexpensive Bayonet Steam Heater

THE ACCOMPANYING SKETCH shows a simply fabricated and portable piece of equipment by which steam heating can be applied in an emergency. This bayonet heater was actually constructed for use on a 30 ft × 9 ft Lancashire boiler shell used as a storage tank for heavy fuel oil where this heating had to be applied from the top of the tank either through existing nozzles or via the manhole. It was found advantageous to use 2-in. nominal bore pipe, Class C, in a 10-ft random length to mount the heater in a vertical position. The extended surface was provided by Sifbronze rods, brazed into the pipe in horizontal circlips, the brazing being in the top surface only of the rod. With the dimensions of heater as sketched and with extended surface ending 3 ft from the top flange, it was found possible to add heat to the oil at the rate of 60 to 80,000 Btu/hr. Since this quantity was greater than that needed for the lagged tank, a Spirax thermostat steam controller was fitted with on/off steam operation.



An "Automatic" Blow-egg

BENZENE SULPHONIC ACID is extremely corrosive, toxic and, due to traces of benzene, has a serious explosion risk. It must be maintained at a predetermined temperature to give a reasonable viscosity without incurring breakdown, and it is therefore essential to have a system which, although simple, will give the requisite accuracy without physical exposure to this liquid. The accompanying diagram indicates the method evolved for the automatic delivery of charges of benzene sulphonic acid to charge pots used in the manufacture of synthetic phenol by the classical fusion process. The method of operation is as follows: A stainless-steel dip-pipe was fabricated to a calculated depth as indicated, and inserted into the corresponding nozzle on the blow-egg.



Initially, the vent valve *A* was opened to vent the blow-egg to the storage tank. Valve *D* is then opened and the charge of benzene sulphonic acid run into the tank until the pressure of the air trapped in the top of the blow-egg balances the hydrostatic head of the acid in the storage tank. The flow of acid then ceases, the vent valve is closed and valve *B* is opened (*D* having been closed) which discharges the benzene sulphonic acid to the charge pot. The non-return valve *C* is fitted in the compressed-air line. The termination of flow of acid is registered by a set pressure on gauge *G* and the evacuation of the blow-egg similarly registered by the pressure falling to zero, when the operation can be recommenced.

The amount of the charge is governed by the depth of the stainless-steel dip-pipe, and since it was frequently necessary to change this, a set of calibrated dip-pipes were made for ready insertion and stamped with the charge quantity. These dip-pipes were made over-long so that any inaccuracies in calculation could be taken care of by machining a slight amount from the fabricated length of the pipe. Since the benzene sulphonic acid tank is a balance tank, variations in level are negligible and do not affect the charge quantity within the requisite tolerances.

Contributions invited

THE EDITOR invites readers to submit, for possible publication in "Process Engineer's Notebook", notes on practical devices that have been elaborated on the job for improving the operation or increasing the safety of processes, or that have been extemporised in special circumstances. The contributions preferably should be of about 250-500 words, and be illustrated with a line diagram or sketch, or a photograph. A minimum of three guineas will be paid for each contribution used. They will be published anonymously or under the contributor's name, according to his wishes.

World of Chemicals

U.S. Chemical Industry

Sales in the U.S. chemical industry reached a total of about $23,200 million in 1958—only slightly under the all-time record of 23.4 billion set the previous year. Profits as a percentage of sales also rose steadily from 9.4% in the first quarter to 10.6% in the final quarter. Production and employment in the industry are rising, though total employment for November, 1958—822,000—did not reach the total for November, 1957. Average inventories of chemicals and related products are equal to about seven weeks' sales. Capital spending for new plants and equipment is expected to rise, but for the early months of 1959 will be below recent record figures according to a review published by the American Chemical Society.

Dividend payments by chemical companies held up better than might have been expected last year, about equalling the 1957 figure. Except in the pharmaceutical field, where business was good through the recession, few chemical firms paid more to stockholders than in 1957. With earnings now going up, dividends look safer. Polyethylene became the leading plastic for the first time, beating vinyls. Its production capacity at year-end exceeded output by 30%.

In the first three quarters of 1958 ammonia production increased about 3%, but the output of other large-volume inorganic chemicals—such as hydrochloric acid, chlorine, sodium hydroxide, nitric acid and sulphuric acid—fell. In the organic chemical field, ethylene glycol and styrene production went up, while formaldehyde, methanol and urea dropped. Price declines for chemicals outnumbered advances in the fourth quarter, and costs of handling and distributing chemicals were rising.

East German Expansion Plans

Some of the outstanding features of the East German chemical programme have been set out in an article in *Die Welt*. They include:

(1) The doubling of chemical production attained primarily by long-term and large-scale financing. During the next six years at least 9000 million marks will be channelled by the State into the chemical industry, now 100% State owned. This compares with a total investment of only 1000 million marks in the chemical industry in the six years 1950-1955.

(2) Only one quarter of the increased output will be obtained from new plant. The biggest single new unit will be a giant combine at Guben for the production of artificial fibres. Total output of artificial fibres is planned to be increased by 460% by 1965.

(3) The principal means of doubling total chemical output will be the rationalisation of labour and equipment. The labour force should increase only from 250,000 to 262,000 in the next six years, but technical experience available in the whole Communist bloc will be pooled for the benefit of the East German Republic.

(4) The Soviet Union will also give direct financial aid to the East German chemical industry. An initial grant of 240 million marks has been promised. It will be repaid by deliveries of chemical products between 1961 and 1965.

(5) Particular attention will be paid to plastics, and production of plastics is to be increased by 250% in the next four years and it is aimed to produce at least 280,000 tons a year by 1965.

The Soviet Union is prepared to supply oil direct by pipeline from the Ukraine.

Reactor Equipment Contract

I.C.I. (Belgium) S.A., as agents for Marston Excelsior, has won an order worth just over £100,000 for aluminium piping in connection with the experimental water-cooled reactor BR.2 now in course of erection at the nuclear research centre at Mol in North Belgium for Centre d'Etudes Nucleaires. Both companies are subsidiaries of Imperial Chemical Industries Ltd. This is believed to be the first large order related to nuclear energy to be obtained by a British firm in Belgium, and is also the first such order to be placed with I.C.I. by a nuclear organisation outside the U.K. It comprises piping and fittings in aluminium alloy up to 30 in. diameter, to connect the reactor shell to the heat exchangers and the exchangers to the cooling pond.

BR.2 is an advanced type of materials and engineering test reactor, using uranium enriched to 90% U235 as fuel with metallic beryllium as the moderator. Heat will not be recovered, but will be removed from the reactor by demineralised natural (not heavy) water.

Mills' Progress

In their regular mid-year report to stockholders, General Mills announced a net income of $7,746,821 for the six months between June 1 and November 30, 1958. This compares with $6,470,000 for the corresponding period last year. Sales for the first half of the company's current fiscal year totalled $274,291,340, an increase of more than $9 million over the $265,094,330 for the same period in 1957. In Minneapolis production began of epoxidised soyabean oil for industry. During the period, the chemical division of the company introduced Versamid 140, a new polyamide resin for industrial uses. The Central Research Laboratories of General Mills announced a new type of electro-static separator, the "E-Machine". The laboratories also produced new biochemical and amino acid products, including L-Histidine, for possible use in pharmaceutical and medical fields. Plans were recently announced for a large new research centre to be built at Minneapolis, at which emphasis would be placed on basic research.

Lincolnshire Oil Find

Oil has been discovered by BP Exploration Co one and a half miles east of Gainsborough, Lincs. A test well drilled by BP struck oil at a depth of some 4600 ft and during tests the well has produced at a rate of 15 tons a day. This new find is about 2½ miles west of Corringham where the company found oil in July 1958, and the company is now preparing to delimit the Corringham field and also the field at Bothamsall, Notts., which it discovered earlier last year. Small accumulations of gas were found in several oil exploration test wells during 1958 and there was further development drilling in the producing oilfields at Plungar, Leics., and Egmanton. Total production of crude oil in 1958 from the existing BP oilfields at Notts., Leics. and Lancs. was about 80,000 tons.

Paper Industry Expansion

Paper producers in the U.S.A. are preparing for a new wave of plant expansion when market conditions, which have improved in recent months, show a substantial and sustained upturn. Continental Can has decided to start construction on a new mill in Georgia, with completion scheduled for early 1961. The plant, on the Savannah River near Augusta, will be able to produce 350 tons a day of bleached kraft paper and paperboard, products which Continental currently buys from outside sources. Other plans in various stages of preparation include International Paper's project for a paper milk container plant at Versailles, Kentucky, to produce up to 35 million containers a month.

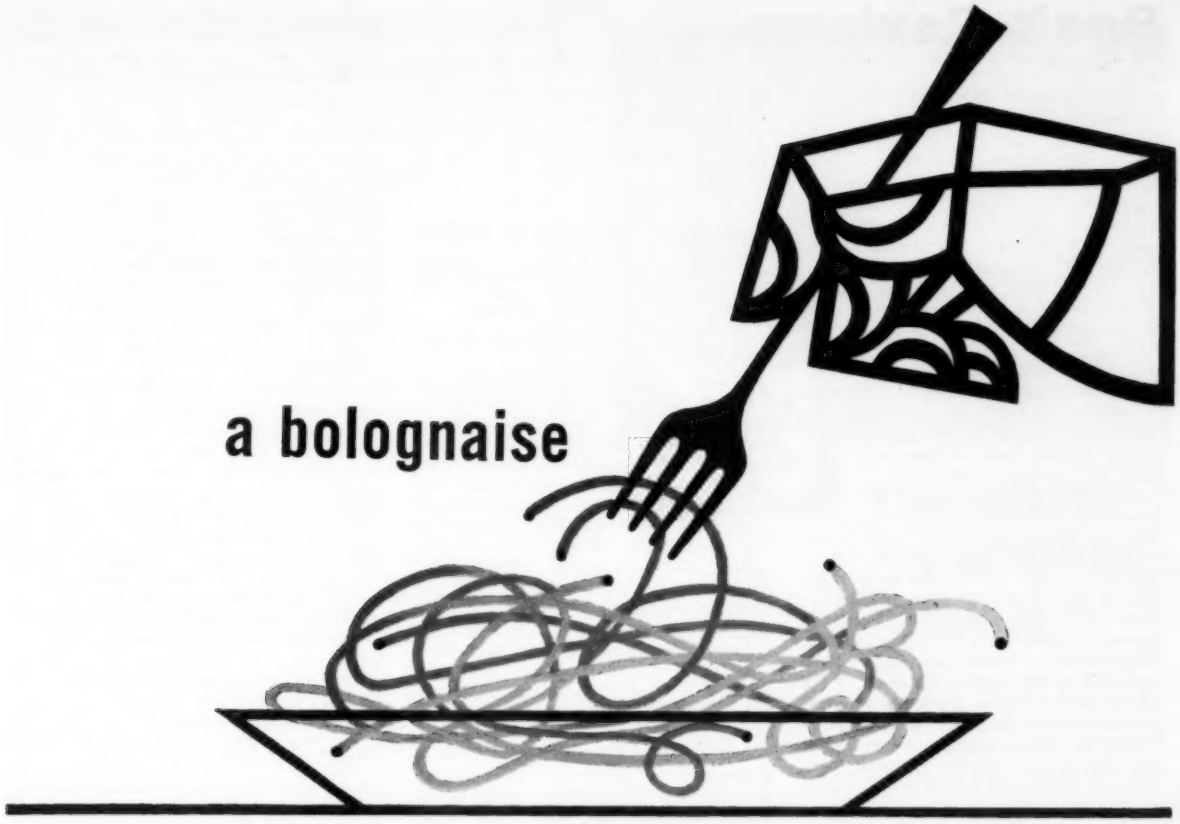
Expansion in Plastics Products

Monsanto have completed a 25% expansion of its production capacity at St. Louis for phthalate esters. The Borden Chemical Co., a division of the Borden Co., has announced that it is to build a $1,500,000 plant to produce polyvinyl alcohol. The plant, expected to be completed by next October, will be designed to produce 5 million lb. annually of polyvinyl alcohol.

The first factory to make synthetic resins in Portugal—RESINTELA—Resinas Sinteticas Lda. was opened near Lisbon recently. It is partly British owned.

I.C.I. in Australia

Opening I.C.I. House, Melbourne, recently, Sir Alexander Fleck said that thirty years ago the capital and reserves of ICIANZ were some £2 million—they now stood at £26 million. The complement had risen from about 400 people to nearly 7000 in Australia alone, and sales per annum from less than £1 million to over £45 million. Thirty years ago about three-quarters of the turnover represented the marketing of imports from Britain. Today the reverse was the case.



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Book Reviews

Modern Chemical Processes—Volume 5
Reinhold Publishing Corp., New York,
Chapman & Hall, London, 1958, 154 pp., 40s.

IN a foreword to the volume, it is noted that these specialised reports have been appearing in the pages of "Industrial and Engineering Chemistry" since 1948. Volume 5 republishes fourteen articles, ranging over a wide field. There is perhaps a general tendency to include much statistical matter relating to the industry in which the process has developed, with a resulting cut in process detail. To many readers this is the more frustrating in that only one process (anhydrite sulphuric acid) is based on European information, though two other articles set out South African practice in gold and uranium preparation. The remaining eleven are accounts of American processes, and the very extensive references to manufacturers of plant will be of relatively little use outside the U.S.A. The text of the various articles is rather broken up by the insertion of illustrations with long captions and even by special "boxed" inserts. Many of the latter could well be incorporated into the body of the article, and some of the photographs of plant might be omitted. The essential process details would then be studied more easily in a continuous text. The flow sheets are excellent, conveying a great deal of information at a glance.

The various articles cannot be reviewed in detail, but a few notable points might be made. Bubble-cap plates appear to hold their own in petroleum distillation despite the many alternatives available. Hydroclones are replacing bowl classifiers in the gold industry, while ion exchange and extraction by organic solvents are of increasing importance in the separation of uranium. The use of a votator heat exchange unit has apparently made "modification" of natural lard possible; and "interesterification" with sodium-potassium alloy as a promoter calls for rapid heat transfer to a thick grease of poor conductivity. In the separation of potassium chloride from borax, the greater rate of crystallisation of the former allows substantial separation even though the mother liquor is supersaturated in both salts. Solvent extraction of cotton seed oil is carried out by slurrying solvent and press flakes and filtering on a vacuum pan filter. This is apparently more satisfactory than the continuous screw or elevator extraction plants working in Europe.

The only British process—sulphuric acid from anhydrite—is carefully surveyed from a chemical standpoint but is a trifle thin on plant detail. The same criticism applies to the article on borohydrides; perhaps this process description might have been held up until more working data were available.

The book is a worthy continuation to its predecessors, excellently printed and contains a vast amount of information. Collection of these specialised articles into book form has justified itself completely over the last decade. The only real objection is that the survey is not as world wide as it might be, with due regard to the international character of the chemical industry.

F. RUMFORD

Electrochemical Processes in Chemical Industries
Albert Regner, Professor of Inorganic Technology, Technical University, Prague.
Translated from the Czech edition.
Artia, Prague, 1957
Constable & Co. Ltd., London, 464 pp., [30s. (paper covers)

AS used in the title of this book, the term "Chemical Industries" does not include processes which might also be classified as electro-metallurgical. Consequently, industrially-important fused melt processes for the electrolytic production of metals such as aluminium, magnesium and sodium are omitted. On the other hand, purely chemical processes which are possible alternatives to electrolytic processes are included. The first half of the book describes electrochemical theory, and the latter part the industrial applications. The theoretical discussion of "overvoltage" is exceptionally concise. More than half the space used to describe processes is allocated to chlorine and chlorine compounds. Processes for the electrolysis of water and the production of hydrogen peroxide are described in some detail, whilst fluorine cells, and some other minor processes, receive attention.

References to recent work in scientific and technical journals are not made, and although industrial information is presented with an international outlook, some inaccuracies such as "The Mathieson Alkali Works at Arvida" appear. Nevertheless, for a technical student the book gives both the basic electrochemical theory and a useful introduction to the electrochemical processes that have been selected. The extent of technical detail is in some instances considerable, but in others would be found inadequate by an industrial electrochemist designing a new production plant. Although the English is sometimes slightly stilted, the meaning is usually clear. The numerous diagrams (which include a cell for high-pressure electrolysis of water "designed by Soviet technicians") are, with very few exceptions, readily intelligible. The book is good value and a useful addition to the literature.

C. M. TUBB

The Solid State for Engineers
by Maurice D. Sinnott
Chapman & Hall, London, 1958, 522 pp., 100s.

THE purpose of this book is to acquaint engineers and engineering students with the basic principles which underlie the behaviour of the solid materials they use. Its composition is based on the analogy with courses in mathematics, physics and chemistry for engineers; this involves a concentration on principles and not on current practice; the why, not the how. A coverage is aimed at that which lies between the handbooks on empirical properties of matter and text-books on the solid state destined for physicists. The author suggests that instructors may select portions of the book for the specific needs of their students, and states his aim of condensing, unifying and simplifying material at present unavailable to the engineer except in specialised higher-level courses outside his field of specialisation. Problems are interspersed throughout the text; the description of the author's own teaching methods indicates that lively and active use has been made of the teaching material contained in this book. DR. SINNOTT is Professor of Chemical and Metallurgical Engineering at the University of Michigan, U.S.A.

Whether the wide range of themes covered will make the book equally useful to engineering undergraduates in the United Kingdom seems doubtful. It is widely felt that with the many new materials becoming available for novel technical applications, some acquaintance with the basic physical and chemical principles underlying their properties is essential even for practical engineers. But some students in specific engineering courses would probably need to go rather more deeply into a much narrower range of selected themes if this kind of instruction is to be of maximum use to them in the long run. Lists of more advanced reading as indicated in bibliographies at the ends of the chapters give a useful guide, but most students would need further help. There are advantages in postponing such deeper instruction to the immediate postgraduate years and in restricting it to students with special requirements. Lecturers in physics to engineering undergraduates will, however, find many stimulating and suggestive ways of presentation in this book, which should make a useful addition to departmental libraries.

A. R. UBBELOHDE

The Encyclopedia of Chemistry (Supplement)
by G. Clark and G. Hawley
Reinhold Publishing Corp., New York.
Chapman & Hall, London, 330 pp., 80s.

THIS supplement adds over 200 articles to the original Encyclopedia. Why some of these are in the supplement and did not appear in the main volume is puzzling in logic, and may be more explicable in terms of production problems. *Plasma physics* or the understanding of *antiparticles*, for example, have advanced fast in recent years, well justifying inclusion in a supplement, but the article on *chemical plant design*—though sound and informative—contains nothing that could not have appeared in the main volume. This is also broadly true of the piece on *chemical process equipment*. Cross-references refer to the main or the accessory volume but the index only to the latter—and the index is of great importance in this work because items are not treated individually with short definitions; composite subjects are discussed in articles of several hundred words each. The contents are always authoritative and those who found the style of the original satisfactory will gain supplementary assistance from its expensive supplement.

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This translation was sponsored jointly by the American Ceramic Society and the National Science Foundation. Although the Conference was held a few years ago, the work is by no means dated: the factual portions comprise a definite contribution to the knowledge available, and the controversial portions will add zest to those concerned with the yet unsolved riddle of the structure of glass.

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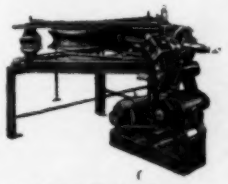

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Tube Tester for Non-magnetic Metals

The C.N.S. tube tester is designed for the rapid location of faults in tubes of non-ferrous metal or stainless steel and for locating corrosion of condenser tubes in steam boiler installations. The equipment is so laid out that the testing can be carried out by untrained personnel once the initial setting has been made by the supervisor. The instrument shows up three types of fault: (a) cracks, inclusions or superficial faults; (b) local changes in wall thickness; (c) corrosion. The equipment consists of a probe or probes containing search coils which are passed around or through the tube specimen. The proximity of the metal occasions certain resistive and inductive changes in the coil characteristics which remain constant so long as the tube metal is consistently homogeneous and free from faults. The probe coils are balanced to give a zero on a meter by resistive and inductive variables inside the main unit. The coils are balanced in a good specimen of the material or in a known good section of the tube itself. The testing is carried out by sliding the probe along the tube and as each fault becomes scanned by the probe the meter zero balance is upset and an indication is given on a meter needle, a warning light and by the ringing of a buzzer alarm. With a high-speed alarm relay testing can proceed at 100 ft a minute. **C.N.S. Instruments Ltd., 61 Holmes Road, London, N.W.5.**

BCE 4944 for further information

Screen for Liquids and Powders

Russell Constructions' new Invicta screen measures 3 ft across the sieve and runs at 3000 rpm. Powders, it is claimed, pass the screen at rates approaching 10 tons an hour and liquids up to 12,000 gallons an hour. Ease of cleaning and maintenance, silence, interchangeability and reliability are advantages claimed for the machine. **Russell Constructions Ltd., Russell House, Adam Street, London, W.C.2.**

BCE 4945 for further information

New Polyester Cement

A new cement has now been marketed which, it is claimed, will permanently withstand the chemical action of both acids and alkalis. Called Alcuma, it is composed of polyester resins, combined with high quality inert fillers, blended to produce an impermeable cement. It comes to the user in the form of a powder and solution, supplied separately. The mixing process is simple, and the cement, which has a soft putty-like consistency, is easily applied. The cement is said to be satisfactory for bedding and jointing, or pointing, vitrified tiles and bricks in the construction of acid- and alkali-resisting floors, benches, tanks and brickwork. It can also be used for jointing and sealing pipes carrying acids and alkalis. **J. H. Sankey & Son Ltd., Refractories Works, Ilford, Essex.**

BCE 4946 for further information

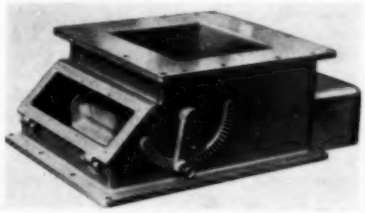
Stainless-steel Mixer

The Manesty Model 200 Stainless Steel Mixer has been produced to meet many requests for a larger machine, based on the design of the familiar Manesty "H" mixer. The new mixer provides a double capacity stainless-steel container for either wet or dry processing. Improved stainless-steel cased seals on the paddle drive shafts ensure efficient sealing of the container and prevent contamination and leakage of the material being processed, it is pointed out. The machine consists of a rigid double-ended cast-iron cabinet carrying the main spindle sleeve and paddle drive at one end and the outboard bearing and tilting gear for the container at the other. The design of the cabinet permits the positioning of suitable trays or receptacles directly underneath the container for direct unloading when the container is tilted. The paddle mounting sleeves are retractable and the paddle can be removed from the chamber for cleaning. The drive from the motor is through a vee belt on to the totally-enclosed worm and wheel. The wheel shaft carries a special retractable driver connecting with the paddle; the design of this driver ensures a positive drive and prevents the ingress of material on to the paddle mounting. The safety guard, made from stainless-steel rods, is just inside the container, and is inter-locked so that on opening it the motor automatically stops. The mixer's capacity is approximately 200 lb. and its motor is of 5 hp. **Manesty Machines Ltd., Evans Road, Speke, Liverpool, 24.**

BCE 4947 for further information

Electro-magnetic Materials Feeder

In the Lea-Bar Vibra Feeder vibration is effected by an electro magnet with variable amplitude control, long strokes being used for lighter material and short strokes for dense granular material.



The units are usually supplied complete with suitable controllers for connecting direct to a single-phase 50-cycle supply. The vibrator pulls the feeder tray sharply back at each pulsation; the tray then returns to its original position at a slightly lower rate by means of leaf and coil springs during the dead period of the magnet. The material falls vertically as the tray is pulled sharply backwards from under it, and it then takes up an advance position relative to the tray, by which it is moved forward by the reciprocating action of the springs. **W. S. Barron & Son Ltd., Gloucester.**

BCE 4948 for further information

New Flow Recorder

The new Arkon Model 1602 flow recorder has been designed to meet the growing demand for a recorder suitable for the measurement of high-pressure gas, compressed air, steam, water and other liquids. The instrument uses the principle of mercury U-tube and float, overload protection being incorporated. It is fitted with a dual valve (instead of the three-cock assembly usually met with in this type of recorder) which incorporates automatic equalising. The visible width of the chart covers 16 hours and a roll of chart lasts six weeks. Where the instrument is required to total the flow automatically, an electrically-operated integrator can be fitted as an optional extra. Charts can be supplied reading in cu. fph, gph, lb./h., in. w.g., differential pressure or any other units to meet users' requirements. Differential ranges from 60 in. to 200 in. w.g. and the recorders are designed for operations under static pressures up to 300 psi. **Walker, Crosweller & Co. Ltd., Cheltenham.**

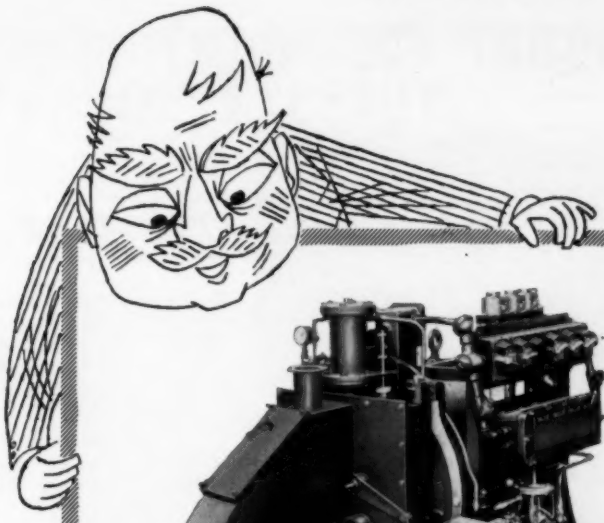
BCE 4949 for further information

Armourplate Glass Tanks

Armourplate glass tanks are the latest industrial-glassware product to be marketed by Q.V.F. The tanks are made of armour-plate glass—polished plate-glass subjected to heat treatment to impart to it increased mechanical strength and resistance to mechanical impact or thermal shock—and advantages claimed for them include durability, transparency and ease of cleaning. In constructing the tanks, precision-worked sheets of the glass are held together by a rigid metal base frame with an external framework of metal tension-rods and corner blocks.

New Sharples Super-D-Hydrators

in the world's most complete range of centrifuges

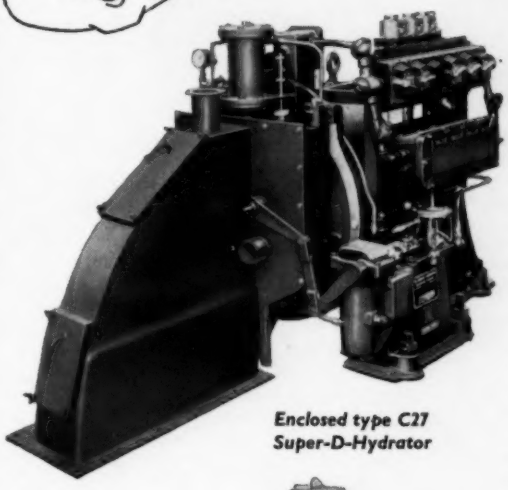


Even before the latest additions, Sharples was the most complete range of centrifuges in the world. Now it's better than ever, with brand new models of Super-D-Hydrator.

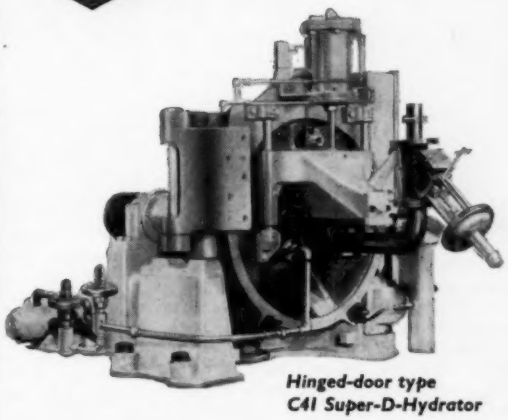
What do the new models mean ? The unique design features of the Super-D-Hydrator are of course retained. High centrifugal force, and completely automatic and continuous operation, continue to supply a solid foundation for the new designs. To these basic characteristics are now added increased capacities and ready availability for inspection, together with the refinements of totally enclosed operation for toxic hazardous materials. Antibiotics can be handled most successfully in a sterile version of the D-Hydrator, while special arrangements can be made for operation at either very high, or very low temperatures. Add up all these designs, and there's a properly tailored answer for every problem of crystal dehydration.

To Sharples world wide experience of some 2500 D-Hydrator installations is now added greater flexibility of operation through the application of careful detailed design, which is the hall-mark, " Sharples."

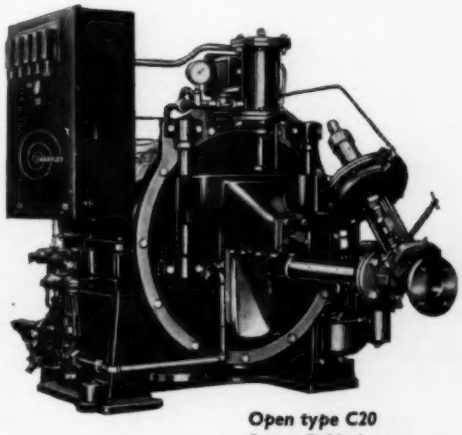
If your problem is the separating, washing and dehydration of any sort of crystal, and you desire consistency of product, combined with automatic and continuous operation, then you are invited to write to the address below or 'phone Camberley 2601 and talk it over with Graham Jackson.



Enclosed type C27 Super-D-Hydrator



Hinged-door type C41 Super-D-Hydrator



Open type C20 Super-D-Hydrator

SHARPLES

SHARPLES CENTRIFUGES LTD., TOWER WORKS, DOMAN ROAD, CAMBERLEY, SURREY. *Telephone: Camberley 2601*

PLANT EQUIPMENT NEWS

The narrow joints are sealed with continuous gaskets, about $\frac{1}{16}$ in. thick, of a material selected to withstand the specific chemical conditions. The tanks are very suitable for coupling to Q.V.F.'s visible-flow pipeline systems. The glass is manufactured by Pilkington Bros. Ltd. **Q.V.F. Ltd., Fenton, Stoke-on-Trent.**

BCE 4950 for further information

Flash Distillation Plants

Buckley & Taylor have designed and are making available Aquaflash water distillation plants. They are produced as a range of standard units for marine purposes in capacities from 25-100 tons per day and are individually designed for large shore installations in sizes of more than 200 tons per hour. The plants are said to be remarkably stable in operation, capable of long periods of service without opening up and to be very economical in heat consumption. Almost any source of waste heat such as gas turbine exhausts, diesel engine cooling water or low- or high-pressure steam may be used. Distillation is effected on the flash principle and as evaporation takes place in open chambers at a relatively low temperature they are virtually immune, the makers say, from problems of scale formation. With the exception of pumps for feed, brine and distillate (which may be duplicated if desired), there are no moving parts. The purity of distillate is suitable for high-pressure boiler make-up.

Incoming raw feed water is passed through the tubes of a series of vapour condensers and is heated in its passage to a temperature of approximately 150°F, whence it is led to a raw water heater where the final heating takes place. From the raw water heater the hot feed enters the first of a series of flash chambers which is maintained under vacuum and a proportion flashes into vapour which is condensed in an associated vapour condenser to form produced distillate. The remainder of the feed is led to a further flash chamber under higher vacuum where a further proportion flashes into vapour and is condensed in another vapour condenser. This process is repeated throughout the three or four stages of the plant, the final stage operating under a vacuum of 28 in. Hg. Plant shells are fabricated in mild steel. The vapour condensers have aluminium brass tubes expanded into brass tubeplates. Brine and distillate pumps of robust marine type are provided with driving motors on a common bedplate. Flash chambers and baffles are coated to minimise the possibility of corrosion. Large land installations may produce 8 lb. or more of distillate per lb. of L.P. feed steam. The largest standard unit, 100 tons a day capacity, 12 ft 6 in. × 12 ft × 9 ft 6 in. in dimensions has a heat consumption of about 373 Btu/lb. distillate. **Buckley & Taylor Ltd., Castle Iron Works, Oldham, Lancs.**

BCE 4951 for further information

Liquid Filters

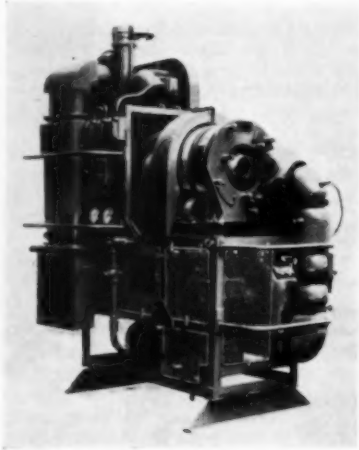
Three new designs have recently been added to the Auto-Klean range of self-cleaning filters for liquids. Auto-Klean 05C, 10GA and 15JA filters, which operate on the principle of defined mesh edge filtration, are of all-metal plate-type construction and are cleaned without interrupting the liquid flow by one complete turn of the handle. They are supplied in a range of filtering meshes from 0.001 in. upwards and magnetic elements are incorporated in each model to give added protection against damage to plant and equipment by ferrous particles. Design developments provide greatly improved flow rates, the manufacturers state, and the new range of filters handles flows up to a maximum of 4000 gal. per hour. The filters are designed primarily for lubricating and fuel oils, distillates, paints and greases, but special models are available for food products, beverages, chemicals and a wide variety of liquids requiring non-standard materials of construction. **Auto-Klean Strainers Ltd., Lascar Works, Hounslow, Middx.**

BCE 4952 for further information

Packaged Rotary Dryer

A small self-contained drying unit suitable for processing a wide range of materials in the form of powders, filter cakes, granules, etc., has been produced by Dunford & Elliott as a packaged version of their Rotary Louvre continuous dryer. Besides drying, it is capable of roasting and cooling. The dryer has a holding capacity of approximately 1 cu. ft of material maximum, and the drying time may be varied between five and sixty minutes. It is estimated that under favourable conditions the unit is capable of evaporating 100 lb. of free water an hour, and it will handle between 1 and 12 cu. ft of material per hour. The installation consists basically of a rotary louvre horizontal drum mounted on four adjustable supporting rollers and driven by a $\frac{1}{2}$ bhp motor through a single reduction gearbox, two fans, inlet and exhaust, powered by a 1-bhp motor with a vee rope drive and an air heater of the direct type with combustion chamber fitted with a Hypact burner and hand control cock. The following percentage moisture reductions have been achieved with inlet temperatures ranging from 120°C to 300°C, varied to suit the material being handled: cellulose acetate, 72.9-2.0; dicalcium phosphate, 5.0-0; polystyrene, 20.8-1.42; sulphate of ammonia, 2.5-0.1. With aspirin a moisture reduction of 5% to 0.1% has been achieved with an inlet temperature of 50°C. The unit may be operated at any temperature of inlet air up to 450°C. **Dunford & Elliott Process Engineering Ltd., Linford Street, S.W.8.**

BCE 4953 for further information



Inert Gas Producer

The Dryer and Gas Plant Division of Birlec is engaged in designing an inert gas generator with a capacity of 200,000 cu. ft an hour. In the design, air mixed with propane is ignited within an enclosed cylinder, and the inert gases generated by the combustion are collected and employed in the purging process. Development work on inert gas generator design is at present being carried out to establish the optimum sizes of burner for a wide range of generator capacities. **Birlec Ltd., Tyburn Road, Birmingham, 24.**

BCE 4954 for further information

Slide and Wedge-gate Valves

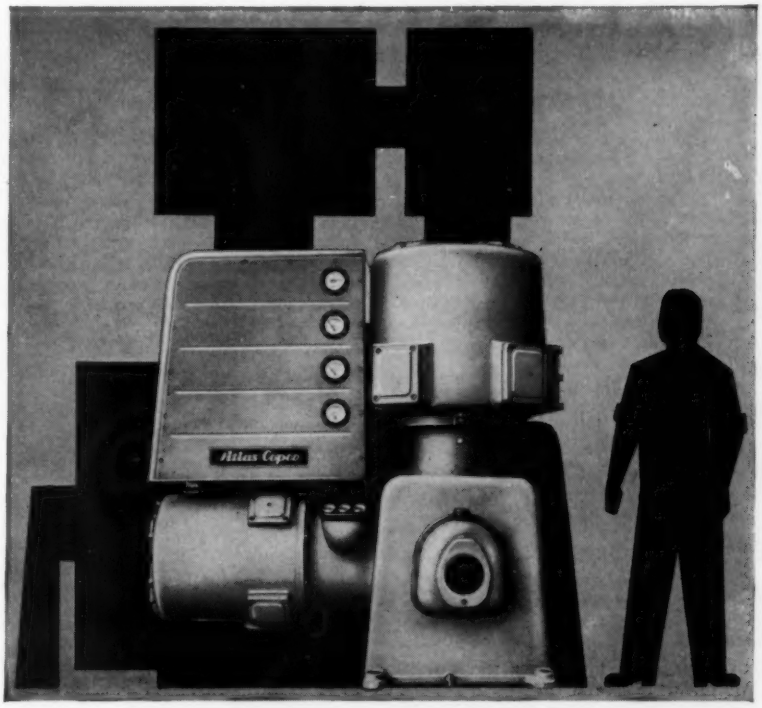
The new Triangle parallel slide valve is of the rising-spindle, outside-screw type and has spring-loaded discs—the springs are to retain the discs in contact with the seats during all conditions, save for the last movement of closure. This feature wipes the seats clean during inter-

BCE 4881 for further information

New Compressor Design

GIVES OUTSTANDING SPACE SAVING WITH REDUCED RUNNING COSTS

The Atlas Copco ER6 is a new stationary compressor which uses fundamental improvements in design to achieve remarkable results in performance and efficiency. The illustration shows the size of the ER6 compared with a conventional compressor of similar output: yet this extraordinary saving in space is achieved with *added* efficiency and economy, and with the same reliability of operation, which has characterised Atlas Copco compressors for 50 years.



Economy of operation

The specific power consumption for the ER6 is 10-15% lower than for most machines of this capacity range on the market. At 4,000 hours running time per year this means an *annual power saving of up to* £360.

In addition the cooling water consumption of the ER6 is very low because of the special design of the intercooler, amounting to only 440 gallons per hour at 60°F. This is less than half the quantity needed for the majority of other similar air compressors.

Economy of installation

The ER6 requires an exceptionally small amount of floor space for its capacity. This reduces the cost of foundation and erection, especially with the use of a flange-mounted motor.

Erection and alignment can be simplified by using a base frame which can be delivered as extra equipment. The balance is so good that the ER6 can be mounted on a skid frame, which does not require a concrete foundation. Skid frame mounting is especially advantageous for contractors and makes it possible for the compressors to be moved easily and at low cost from one site to another.

The ER6 is equipped with an oil pressure control device and cooling water gauges together with a full set of instruments for visual control.

PRINCIPAL DATA

Maximum pressure in psi	Speed in rpm	Low-pressure piston displacement in cfm	Free air delivered at 100 psi in cfm	Cooling water required at 60°F approx in galls/hour	Weight in pounds
125	485	1,300	1,075	440	6,600

A complete range of compressed air equipment

Atlas Copco manufactures portable and stationary compressors, rock-drilling equipment, loaders, pneumatic tools and paint-spraying equipment. Sold and serviced by companies or agents in ninety countries throughout the world.

Atlas Copco PUTS COMPRESSED AIR TO WORK FOR THE WORLD

Contact your local company or agent or write to Atlas Copco AB, Stockholm 1, Sweden

C.30-1 G.B.

PLANT EQUIPMENT NEWS

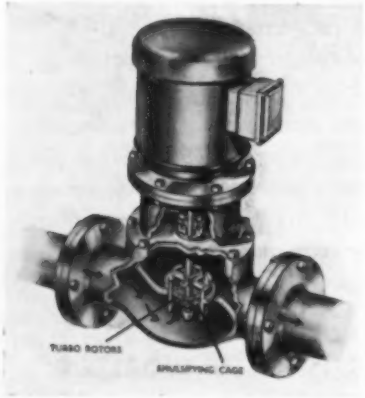
mediate travel and permits a clean contact between the outlet (downstream) disc and seat faces. The shut off of this valve is thus commensurate with the line pressure. On sizes up to 4 in., limited alignment is provided by male/female or telescopic connection of the two discs, whilst on larger sizes a similar function is provided by a carrier ring (belt ring) and a disc clip. The ring is of stainless steel to avoid rust which otherwise precludes free rotation of the disc; the carbon steel clip prevents undue outward movement of the discs when in the open position. A steel stop or crosshead is keyed to the spindle to prevent rotation and slides between two steel pillars provided with collars limiting the travel. A bridge at the upper end of the pillars carries the sleeve which will not permit the stem assembly to fall if the handwheel is removed with the valve open. A three-bolt gland is featured giving even adjustment and the gland skirt protects the studs from atmospheric damage. A tubular cap completes the assembly, giving protection to the upper portion of the stem. The maximum working pressures are: steam, 250 psi (850°F maximum); cold water, oil and air—sizes up to 6 in. 600 psi, above 6 in. 450 psi.

Another new-comer to the Triangle range of valves is the cast-iron wedge gate valve, series 125. It has been designed with body and bonnet and integral yoke in cast iron to BS 1452, grade 14; bolted body-bonnet connection; outside screw and yoke; stem rising through handweel; suitable for repacking under pressure when fully open; bronze trim; ends flanged and drilled to BS 1575:1949 with smooth face finish. They are recommended for saturated steam service at 125 psi or liquid and gas at or near atmospheric temperature at pressures up to 175 psi. **Triangle Valve Co. Ltd., 315 Regent Street, London, W.1.**

BCE 4955 for further information

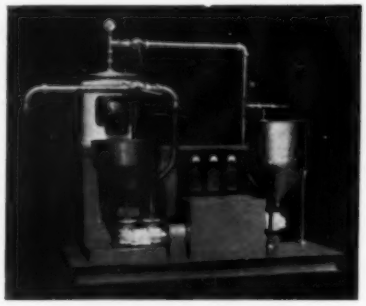
Continuous Pipeline Mixer

Wm. Boulton have developed the Thrumix continuous pipeline mixer. It is manufactured in the range of sizes from 1 in.-6 in. bore and can be made in cast iron, stainless steel or the other constructional metals. The straight-through design of the Thrumix enables it to be inserted in a pipeline without the need for the introduction of bends or tees to accommodate the unit. The principle employed in the mixer is a very high degree of shear and an easily obtained controllable degree of recirculation. Small horse-power motors, ½-2 hp, only are required. Either a standard stuffing-box or mechanical seal is fitted, as required. Depending on the viscosity of the materials, the throughput varies from approximately 14 gal. a minute to 400 gal. a minute. Anything that can be pumped will pass through the mixer, the makers point out; and owing to its simplicity it is suitable for use in continuous processes where an agitated tank is at a disadvantage. **Wm. Boulton Ltd., Providence Engineering Works, Burslem, Staffs.**



BCE 4956 for further information

Grease Milling and De-aerating Unit

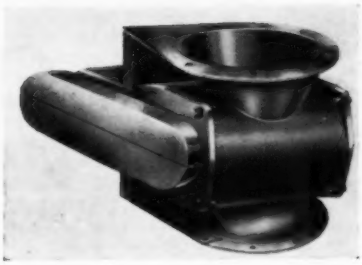


Premier Colloid Mills have developed a new self-contained grease milling and de-aerating unit which has an output of up to 5000 gph and handles sodium, lithium and Bentone greases. Either continuous or batch production can be employed. The raw grease is pumped from the hopper into the unit's colloid mill, where it is rapidly softened. A frothy mixture, caused by an unavoidable mixing with the air, is pumped into a de-aerating plant, consisting basically of an enclosed cylinder. Passed diametrically through this cylinder is a metal plate with a pattern of fine holes. To permit variations in screen the plate is interchangeable. On the underside of the plate is a high vacuum produced by a pump, which draws the frothy grease through the fine holes and causes the air bubbles to burst. **Premier Colloid Mills Ltd., Walton-on-Thames, Surrey.**

BCE 4957 for further information

Airlock and Feeder

The improved rotary Mikro Airlock has been designed to overcome the difficulty of mechanically feeding materials through a pressure differential and at the same time preventing air or gas from being fed with such materials. The airlock consists of a fabricated cylindrical



housing inside which rotary vanes slowly revolve, conveying material from an upper chamber and dropping it by gravity into a lower receptacle—such as a barrel. The rotary vanes are usually tipped with flexible plastic materials to provide a seal between these tips and the inside walls of the housing. New types of vanes of various compositions are available to meet varied requirements, all designed to prevent the feed materials from binding the rotor and to provide longer life. All of the inside surfaces of the Mikro airlock are finished for close clearance.

The motor and drive which can be of the belt, chain, direct coupled or coupled or variable-speed, are located on the same side of the unit so that the rotor may be easily removed for the replacement of vane tips. The equipment can be used for a wide variety of pressure change applications, and there is one basic housing design to cover this range. Standard materials of construction are carbon steel/cast iron or stainless steel. Other materials can be used to suit special applications. The standard sizes available are 5-, 8-, 12-, 18- and 24-in. diameters, giving an output coverage from 10-6500 cfh.

Another new product from Pulverizing Machinery is a hopper-type material feeder of 2 cu. ft capacity. Called the Mikro-Feeder, it has been designed to give an accurate, constant and uniform flow feeding of any wet or dry substances, other than those which are viscous or semi-viscous. It consists of a vertical rotating-shaft on which is mounted a circular feed-plate and a steel hopper 15 in. in diameter and 21 in. high. The rotating shaft, feed-plate and hopper are mounted on a steel housing over the drive motor and reducer-gear. Secured to this housing is a shearing-knife, which slides between the base of the hopper and feed-plate. When the feeder is in action, the hopper, filled with material, revolves, and the shearing-knife at its base shears off just enough of the substance to maintain a chosen feed-rate.

The rate may be varied from a few pounds to 5000 lb. per hour, depending, of course, on the density and texture of the substance being handled and an accuracy of ±1% can be maintained, it is claimed. The makers supply the following capacity figures in lb.p.h, maximum and minimum: Powdered alum, 2400, 12; ground bauxite, 3400, 17; cement, 4800, 24; ground gypsum, 2800, 14; granulated sugar, 2800, 14. **Pulverizing Machinery Ltd., Dover Street, London, W.1.**

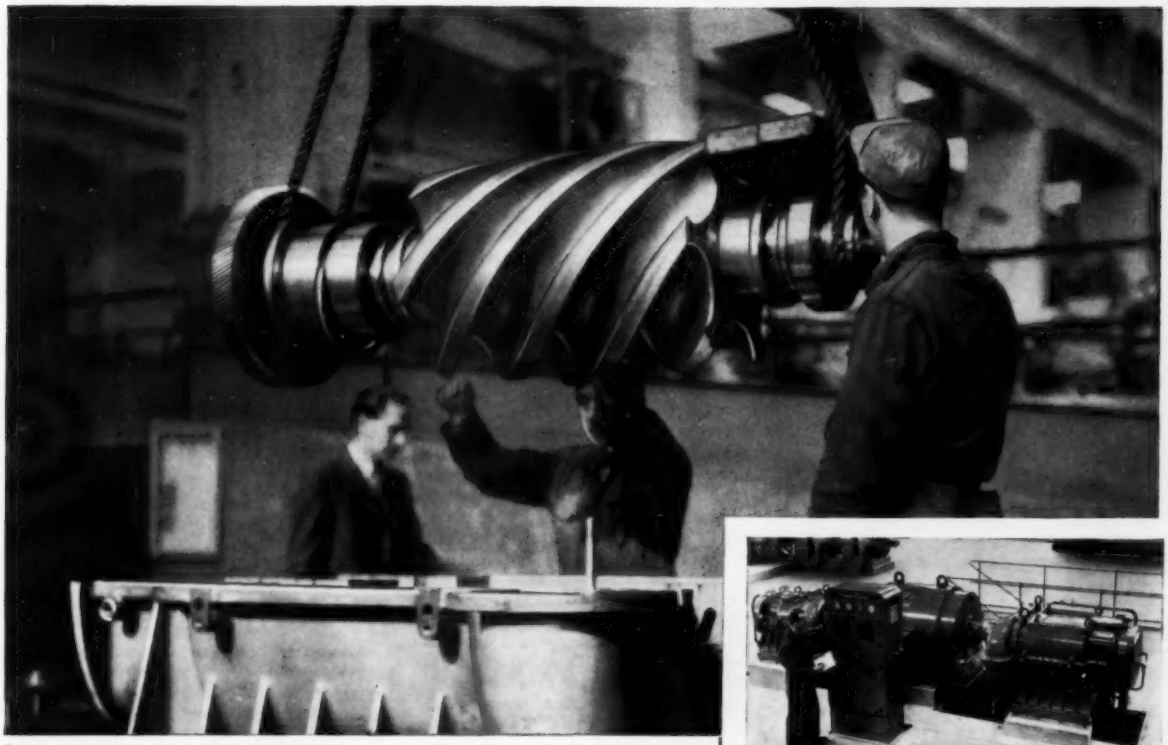
BCE 4958 for further information

BCE 4882 for further information

A New Rotary Screw Compressor

THE ATLAS COPCO

TWIN-AIR



Fitting the female rotor in a Twin-Air compressor.

NO METALLIC CONTACT BETWEEN COMPRESSION COMPONENTS— this means *no wear*. . . long intervals between overhauls . . . minimum maintenance.

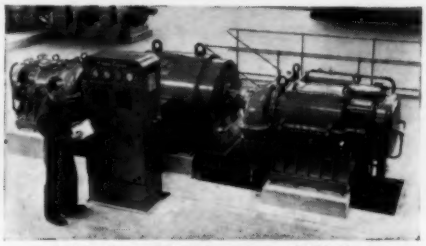
HIGH EFFICIENCY — cuts power waste—and operating costs.

SPACE SAVING — simple, compact design effects marked reduction in installation costs.

SMOOTH AIR FLOW — no 'surging' or 'pumping' characteristics.

OIL-FREE AIR OR GAS — no lubricant is present in the compression chamber.

LESS SENSITIVE TO IMPURE AIR — because compression components are not in metallic contact.



An Atlas Copco 'Twin-Air' compressor (8,100 c.f.m.) at the Grängesberg mine, central Sweden.

BASED ON A SWEDISH INVENTION

Atlas Copco Twin-Air compressors—based on the original design of the Swedish Inventor, Lysholm —have already been fully tested at Kiruna in the Arctic Circle area of Northern Sweden. Here, at the world's largest underground iron mine, they have been operating under normal working conditions for two years.

NOW A TWIN-AIR PORTABLE!

Atlas Copco introduces the *world's first* PORTABLE Rotary Screw Compressors! These portable machines embody all the know-how gained from two years operating experience with Twin-Air Stationary Compressors. The first models in this new range are machines of 370 c.f.m. and 620 c.f.m. Both 100% air-cooled, diesel-powered units.

Atlas Copco PUTS COMPRESSED AIR TO WORK FOR THE WORLD

For details of the new Atlas Copco Rotary Screw Compressors, contact your local company or agent or write to Atlas Copco AB, Stockholm 1, Sweden, or Atlas Copco (Great Britain) Limited, Beresford Avenue, Wembley, Middlesex

C.34/B

PLANT EQUIPMENT NEWS

PHYSICAL SOCIETY'S EXHIBITION

The Physical Society's Exhibition of Instruments and Apparatus, 1959, was held in London in January this year instead of in the Spring, as of late. Below are notes on some of the equipment shown.

Plant-Stream Gas Analyser

The new Mervyn plant-stream gas analyser will measure and record the amount of one component in a multi-component gas stream. Gases that have been successfully tried include ammonia, oxygen, carbon monoxide, carbon dioxide, sulphur dioxide and hydrogen sulphide. The stream gas is sampled and passed through an absorber column, where it reacts with a suitably chosen reagent. The resulting change in conductivity is a function of the desired component's concentration. **Mervyn Instruments, Copse Road, St. John's, Woking, Surrey.**

BCE 4959 for further information

Ultrasonic Fatigue Tester

An ultrasonic fatigue tester developed by Mullard Research Laboratories operates at an ultrasonic frequency (20 Kc/s = 1,200,000 cycles/minute) and provides greatly accelerated testing over conventional methods. Fatigue limits measured at 20 Kc/s are rarely identical with low-frequency figures it is pointed out, but the discrepancy is never large. At stresses near the fatigue limit the dissipation due to mechanical hysteresis increases rapidly. For some materials giving high acoustic losses, it is necessary to supply external cooling; for example, by a stream of forced air over the central region of the specimen. **Mullard Research Laboratories, Cross Oak Lane, Salfords, near Redhill, Surrey.**

BCE 4960 for further information

Zone Melting and Water Sampling

An improved apparatus for floating-zone melting by electron bombardment was exhibited by the National Research Development Corporation. Its special features included: (a) a work chamber with adequate cooling and easy access to the interior; (b) good visibility of the specimen during refining; (c) permanent alignment of the upper and lower specimen chucks and cathode traverse mechanism; (d) a high-speed pumping system to ensure a vacuum in the 10^{-4} mb range or better, even when considerable outgassing of the specimen takes place; (e) automatic control of a zone refining cycle with zone speeds ranging from 0-135 in./hr, and bombarding power ranging from 5 kW to a few mW. The designers are F. E. Birbeck and A. Calverley, of the Services Electronics Research Laboratory.

An automatic water sampler, developed for taking samples at predetermined times from channels, streams and open tanks, which is self-contained, portable and proof against moderately severe weather conditions, was also shown by N.R.D.C. It consists of a number of sample bottles of adequate size (for example, 12-oz medicine bottles), each of which is roughly evacuated by a manual or electric pump and connected by a tube to the source from which the samples are to be taken. Part of this tube consists of rubber pressure tubing which is closed by a catch which may be released by discharge of a condenser through a relay coil. Release of a catch, therefore, allows the sample to be forced by atmospheric pressure through the tube and into the sample bottle. A timing device provides for the release of the catches at the required times. **N.R.D.C., 1 Tilney Street, London, W.1.**

BCE 4961 for further information

N.M.R. Spectrometer

Fairey Aviation have for some time been engaged on the development of nuclear magnetic resonance spectrometers for research, chemical analysis and process control applications. The first equipment to be introduced will be a high-resolution N.M.R. spectrometer, available in June. It has been designed for the chemical analysts and the research workers who require a resolution sufficiently high to show chemical shift and spin splitting, at a cost comparable with that of other types of moderately-priced laboratory spectrometers. The resolution, which is of the order of 0.5 to 1 milligauss (in a field of 5000 gauss), has been achieved with a comparatively small permanent magnet. The electronic circuitry has been reduced to a minimum and simplicity of operation has been a primary design consideration. **The Fairey Aviation Co. Ltd., Heston Aerodrome, Hounslow, Middx.**

BCE 4962 for further information

Average-temperature Indicator

Sangamo Weston's Model S229 average-temperature indicator comprises a 6-in. scale indicator complete with element selector switch, housed in a weatherproof cabinet. The indicator is of the ratiometer pattern which is unaffected by variations in the voltage of the supply. It is intended for use with an "intrinsically safe" transformer having a secondary voltage of 12 volts. This transformer will normally be housed in the site substation, whilst the indicator, under a suitable canopy, is usually located in the open, adjacent to the storage tank. The indicator is available with any one of the following ranges: 0° to +120°F; +30° to +150°F; +60° to +180°F. The instrument's accuracy is stated to be ±1°F. **Sangamo Weston Ltd, 22 St. Georges Court, New Oxford Street, London, W.C.1.**

BCE 4963 for further information

New Publications

A new Wellington publication is devoted to the company's range of heat exchangers. The book shows how their products are designed and manufactured under unified control, and it includes tables of heat-exchange materials and characteristics of heat exchanger tubes. The company has also produced leaflets of their gilled tubes and air-cooled heat exchangers, publications 158, 358 and 258. **Wellington Tube Works Ltd., Great Bridge, Tipton, Staffs.**

BCE 4964 for further information

A 40-page reference book providing tables of weights of aluminium plate, sheet, coil, strip, circles, bars, tubes, etc., is available from the **British Aluminium Co. Ltd., Norfolk House, St. James's Square, London, S.W.1.** Conversion tables to Imperial, American, Stubs, Birmingham Sheet, etc., are included.

BCE 4965 for further information

Humphreys & Glasgow have published a 48-page illustrated book to illustrate the scope of their services. The book deals with gas production, gas treatment, integrated chemical installations, including plant for ammonia, methanol and urea, briquette carbonisation and nuclear power. **Humphreys & Glasgow Ltd., 22 Carlisle Place, London, S.W.1.**

BCE 4966 for further information

A.P.V.'s latest booklets are devoted to batch benzole plants, their plate evaporator and alcohol and yeast plants. The booklet on their plate evaporator includes a line diagram and an "exploded" view of the apparatus to illustrate the platage for one complete feed pass. **The A.P.V. Co. Ltd., Manor Royal, Crawley, Sussex.**

BCE 4967 for further information

Fisher's new 28-page illustrated booklet punched for filing outlines the company's range of valves, regulators, controllers and other pieces of equipment that are made now in Britain. Cut-away illustrations and abbreviated specifications are given for the products described. Their bulletin 431-GB is devoted to their type 431 blending unit, which is being developed for the in-line blending of intermediate grades of fuel oil. **Fisher Governor Co. Ltd., Airport Works, Rochester, Kent.**

BCE 4968 for further information

The range and application of their wire gauzes are described in a leaflet just published by **Endecotts (Filters) Ltd., Lombard Road, London, S.W.19.**

BCE 4969 for further information

An eight-page booklet by Cochran & Co. illustrates some of the welded pressure vessels that the company has made recently. They include carbon dioxide containers 4 ft 6 in. by 15 ft, 350 psi, and a steam accumulator 40 by 60 ft, 60 psi. **Cochran & Co. Ltd., Annan, Dumfriesshire.**

BCE 4970 for further information

High Duty Alloys have published a brochure outlining the die-casting properties of their alloys, Hiduminium and Hiduminium 10. **High Duty Alloys Ltd., Slough, Bucks.**

BCE 4971 for further information

pH and Quality Control

In many processes and undertakings pH plays an important part in determining quality and yield. Among the benefits to be gained from automatic control of pH are : improved quality and uniformity, reduction of waste, conservation of reagents; and protection from corrosion or pollution.

The Kent Universal pH Indicator/Recorder/Controller is a typical example of the many contributions made by KENT towards fully automatic adjustment of a plant's physical conditions. It is an accurate, robust and dependable equipment incorporating an air-operated controlling unit which automatically corrects any deviation in desired pH value by means of a regulating unit. The regulating unit can take the form of a diaphragm-operated control valve for direct installation in the pipe-line, a power cylinder for operating valves etc., or an open dosing trough for regulating reagent feed.

New miniature primary element for flow-line and immersion

KENT have recently introduced this miniature primary element for pH measurement, using a glass electrode as the pH responsive element. The use of electrodes which are extremely robust and long lasting is possible because of the sensitivity of the KENT continuous-record measuring system.

Both electrodes and resistance thermometer are permanently sealed into an easily replaced and inexpensive assembly unit. The element is completely impervious to water vapour; can be totally immersed in boiling solutions for long periods with very little maintenance.

Further information is given in Publication BC 158, obtainable on request.

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Month's News in Brief

New Gas Processes

Much of the research work carried out by the London and the Midlands Research Stations of the Gas Council has now reached a stage when it is ready for commercial development. With this in mind, the Gas Council has announced that it has entered into agreements under which the following companies are licensed to build commercial plants at home and abroad, covering developments relating to the production of gas from coal and oil, which are characterised by operation under a pressure of several atmospheres. The companies are: Woodall-Duckham Construction Co. Ltd., Humphreys & Glasgow Ltd. and Henry Balfour & Co. Ltd.

The developments referred to by the Gas Council may well be those which Dr. J. Burns (North Thames Gas Board) mentioned in discussion to the "Conference on the Use of Small Coal—Today and Tomorrow", held during May of last year. Speaking of processes being developed in this country, he said: "I would particularly mention the Gas Council's work on the hydrogenation of coal . . . (however) operations were being first directed to the hydrogenation of oil with a view to going over to coal later."

£100,000 Belgium Contract for I.C.I.

I.C.I. (Belgium) S.A., as agents for Marston Excelsior Ltd., Wolverhampton, have obtained an order worth just over £100,000 for aluminium piping in connection with the experimental water-cooled reactor BR.2 now in course of erection at the nuclear research centre at Moll, in North Belgium, for Centre d'Études Nucleaires. Both firms are subsidiaries of Imperial Chemical Industries Ltd. This is believed to be the first large order related to nuclear energy to be obtained by a British firm in Belgium, and is also the first such order to be placed with I.C.I. by a nuclear organisation outside the United Kingdom. It comprises piping and fittings in aluminium alloy, up to 30 in. diameter, to connect the reactor shell to the heat exchangers and the exchangers to the cooling pond. Marston Excelsior Ltd., specialists in the fabrication of aluminium alloy, will supply the pipes and fittings and carry out all the site-welding at Moll, as well as supervising erection by the Belgian firm "Fabricom".

Merl Research Summaries

The Mechanical Engineering Research Laboratory, D.S.I.R., is preparing short summaries of the results of recent research of direct industrial interest to help firms to keep in touch with its work. They will give straightforward accounts of work still in progress at MERL as well as the main findings of completed investigations. They are intended for circulation to senior management as well as to design and production staff. Among subjects covered from time to time will be fatigue and creep of engineering materials and components; bearings, lubrication and wear; performance of gears and other mechanisms, engineering metrology and noise control; design and performance of hydraulic machinery; heat transfer and applied thermodynamics; and machinery, extrusion and other metalworking processes. Engineers and industrial organisations who would like to receive copies of MERL Research Summaries are invited to send their names to The Director, Mechanical Engineering Research Laboratory, East Kilbride, Glasgow.

Atomic Energy Information

An Information Centre has been opened at 11 Charles II Street, London, S.W.1, the London office of the United Kingdom Atomic Energy Authority. Its purpose is to provide a convenient centre in London where members of the public, commercial firms and other organisations may consult published unclassified material and seek advice on sources of information on United Kingdom atomic energy matters. A collection of U.K.A.E.A. Unclassified Reports is available for reference. Indices and abstracts of atomic energy literature are filed and publications about the work of the United Kingdom Atomic Energy Authority are available. Next to the Centre is a photographic library which holds a collection of some 8000 photographs covering many aspects of atomic energy. Prints may be purchased out of stock or ordered to suit particular requirements. The library also holds stocks of slides in both colour and black and white which are available on loan. The Information Centre and the Photographic Library are open from Mondays to Fridays inclusive between 9.30 a.m. and 5 p.m. In order to make atomic information more easily available, the Authority has also decided to make fuller use of microphotography. The effect of this will be to make all non-secret reports which have been prepared since 1947 readily obtainable. Complete sets are also being presented to a number of other countries and to certain international agencies. In addition to this, the Authority is increasing its facilities for supplying reports in conventional form as they are prepared.

News Briefs

In the article by S. J. D. van Stralen, "Heat Transfer to Boiling Binary Liquid Mixtures", Parts I and II, published in the January and February issues of *British Chemical Engineering*, a number of errors of minor importance occurred.

In Part I, Fig. 1: Read "R = neoprene packing" for "N = neoprene packing"; and "*U = upper nickel-coated ring*" was omitted. In Fig. 12—4: Read "*4.1*% wt. of M.E.K. at a pressure of 21 cm Hg" for "*41*% wt. of M.E.K. at a pressure of 21 cm Hg". In the caption under Table 2: Read "A slight superheating $\triangle\tau$ of the boiling liquid . . ." for "A slight superheating $\triangle T$ of the boiling liquid . . .".

In Part II, in the caption of Fig. 13 (diagram of first stainless-steel boiling boiling vessel): P = teflon packing was omitted.

The merger of The British Tabulating Machine Co. Ltd. and Powers-Samas Accounting Machines Ltd. into a combined company, called International Computers & Tabulators Ltd. (I.C.T. for short) has been announced. The initials I.C.T. are to be adopted for general use both in trading and financial connections. I.C.T. employs between 15,000 and 16,000 staff and its assets are valued at nearly £24 million. Throughout the 50 years of its existence, The British Tabulating Machine Co. had built up a remarkable business of renting "Hollerith" electromechanical punched card equipment and electronic computer machines. Its operations were conducted almost entirely within the United Kingdom and Commonwealth countries. Powers-Samas, during its 43 years of life, had correspondingly built up a highly successful business with similar institutions and organisations by both renting and selling mechanical and electronic punched card equipment. Powers-Samas operations overseas extended beyond the Commonwealth countries to the Continent and, on a small scale, to North America.

Integra, Leeds & Northrup Ltd.'s associates, The Leeds & Northrup Co. of Philadelphia, have received a contract valued at £225,000 from the Argonne National Laboratory for complete instrumentation and control systems for the Experimental Breeder Reactor No. 2 (EBR-2), now under construction at the Atomic Energy Commission's National Reactor Testing Station. This is reported as the largest contract ever placed for any single reactor facility. The whole range of instruments involved in this contract are manufactured by Integra. Leeds & Northrup Ltd. at their Birmingham factory.

Metal & Pipeline Endurance Ltd. have recently been appointed as official consultants and cathodic protection designers for the Government of Trinidad and Tobago The work will cover all types of new underground structures and pipelines in these islands.

A second course on the Control and Instrumentation of Reactors will be held at the Harwell Reactor School from July 7-17, 1959, inclusive, and will be open to British and overseas students. Courses for senior technical executives in industry are held at the Harwell Reactor School. The next of these courses on which places are available will be held from June 15-25, 1959. Details of both courses from The Principal, Reactor School, Atomic Energy Research Establishment, Harwell, Didcot, Berks

Adolph Hess & Bros. Ltd. have been appointed as the agents for the Nopco Chemical Co of New Jersey in the United Kingdom and Eire.

BCE 4884 for further information

"SPEEDIVAC" INDUSTRIAL ROTARY VACUUM PUMPS

Industry has already shown considerable interest in the new large capacity "Speedivac" pumps for vacuum drying, distillation, deodorising, degassing, impregnation and many other processes of a similar nature. Long experience has enabled us to produce a series of single-stage pumps robust in construction to suit the industrial market, yet still retaining the characteristic features and styling of our smaller "Speedivac" models.

Model Number	Permanent Gas. Ult. Vacuum mm Hg		Displacement	
	Without Gas Ballast	With Gas Ballast	Ft³/min	Lit/min
ISC 900	0.01	0.5	33.5	950
ISC1500	0.01	0.5	50	1415
ISC3000	0.01	0.5	100	2830

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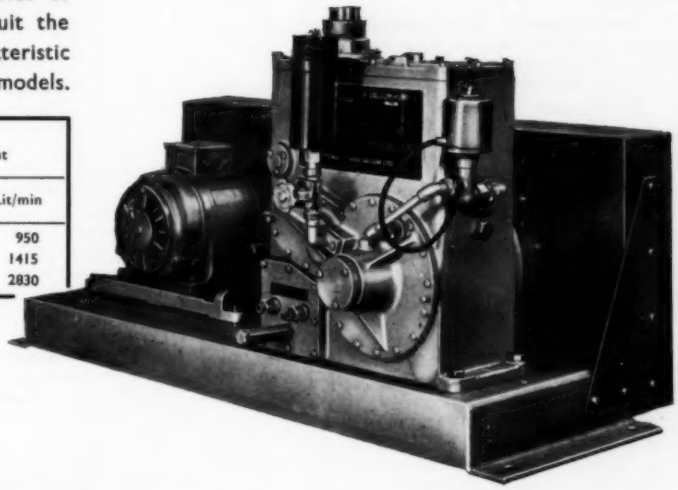
The "Speedivac" ISCI500 pump outfit (approximately 1/12th full size).



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BCE 4885 for further information

James Gordon Valves Ltd. has been formed to take over the valve activities of James Gordon & Co. Ltd., a member of the Elliott-Automation Group. The new company will handle the design, manufacture and sale of the specialised Gordon range of control valves. The company will have its head office at Airport Works, Rochester. The directors are G. C. Fairbanks, H. Masheder, J. E. O'Breen and H. R. Walton.

Sunvic Controls Ltd. announce that their London office is now at Crown House, Aldwych, London, W.C.2. Tel.: TEMple Bar 8040.

Prat-Daniels (Stroud) Ltd., Glos., makers of fans and grit and dust collectors, have moved their London office to 62/3 Fenchurch Street, London, E.C.3. Tel.: ROYal 4122 and 6305.

People in the News

Sir William Scott, managing director of Armstrong Whitworth (Metal Industries) Ltd., and **Sir Richard Bellingham Graham** have been appointed directors of Head Wrightson Teesdale Ltd., a subsidiary company of Head Wrightson & Co. Ltd.

Esso Petroleum Co. Ltd. announces that **Mr. H. C. Tett,** formerly a managing director and chief executive, has been appointed chairman and managing director following the retirement of Sir Leonard Sinclair.

Mr. C. Dotson of Dallas, Texas, U.S.A., has been appointed chairman of the Board of Texas Instruments Ltd., Bedford, first European subsidiary of the American organisation and manufacturers of silicon semi-conductors (transistors) in this country. An extensive new plant is planned for erection on a site of 240,000 sq. ft at Hoo Farm, Bedford. Building will commence early in 1959 and by 1963 it is expected that 1400 people will be working for the company.

Mr. J. Simpson has been appointed deputy chairman and **Mr E. N. Wenborn** as joint managing director of Woodall-Duckham Construction Co. Ltd. as from January 1, 1959.

Mr. G. K. Hampshire, chairman of I.C.I.'s General Chemicals Division, and **Dr. J. S. Gourlay,** chairman of the Paints Division, have been appointed to the Board of I.C.I.

Mr. C. E. Walters has been appointed general sales manager of Sunvic Controls Ltd. covering all of the company's products but, in addition, is retaining responsibility for the Domestic Products Division.

Metropolitan-Vickers Electrical Co Ltd. announces the appointment of **Mr. H. West** as assistant managing director.

Mr. J. M. Storey, managing director of Dewrance & Co. Ltd., has been appointed vice-chairman of The Council of British Manufacturers of Petroleum Equipment. Mr. Storey, who was awarded the C.B.E. in the New Year's Honours List, was the leader of the Council's "Economic, Technical and Goodwill Mission" to Canada in 1957.

Mr. Gordon Helps, joint managing director of Humphreys & Glasgow Ltd., of London, has retired, some twelve months short of normal retirement age, on account of ill health. He is 63, He was also a director of Gaz à l'Eau, the French associate company of Humphreys & Glasgow Ltd., and was concerned with work carried out on the Continent over a number of years in association with Demag of Duisburg.

Mr. B. Pollard, of Constructors John Brown Ltd., left by air for New York on January 13, to establish an office for the sale of Kittel plates in the United States. Constructors John Brown Ltd. has held the licence for the design, manufacture and sale of Kittel plates within the U.K. and Commonwealth since 1954. The company recently acquired similar rights for the U.S.A. Initially Mr. Pollard will be staying at Hotel Commodore, 109 42nd Street, Lexington Avenue, New York City, N.Y.

Nuclear Chemical Plant Ltd., of 22 Carlisle Place, London, S.W.1, the company recently formed jointly by The Power-Gas Corporation Ltd., Humphreys & Glasgow Ltd. and John Thompson Ltd., announce the appointment of **Mr. R. W. Rutherford,** joint deputy managing director of The Power-Gas Corpration Ltd., as chairman, and **Mr. C. Gresle Farthing,** deputy chairman and joint managing director of Humphreys & Glasgow Ltd., and **Mr. J. H. N. Thompson,** deputy chairman and joint managing director of John Thompson Ltd., as directors. **Mr. C. J. Carter, Mr. C. Robson** and **Mr. N. H. Williams** have been appointed alternate directors. **Mr. R. Jowitt** has been appointed general manager and **Mr. E. J. G. Good** secretary.

Mr. R. C. Dickie, works general manager of Marchon Products Ltd., Whitehaven, has been appointed to the board of directors, and **Mr. O. Secher,** a director of the company in charge of sales, has been appointed to the board of Solway Chemicals Ltd. Both companies are members of the Albright & Wilson group.

Mr. J. T. Black, general sales manager of Polymer Corporation Ltd., Sarnia, Canada, recently announced a number of managerial appointments in the marketing division of the company. The various responsibilities in the division were reorganised under the following personnel: **Mr. S. C. Kilbank, Mr. J. T. Fitzgerald. Mr. T. L. Davies, Mr. E. E. Gale** and **Mr. W. W. Winskill.** Mr. Kilbank was named area sales manager for Europe, the Middle East and Africa. Mr. Fitzgerald was appointed area sales manager for South America, Mexico and Australasia. Mr. Davies was named area sales manager for Canada and the United States.

Mr. R. J. Wingrove, of Lichfield, has been awarded the William Macnab Medal of the Institution of Chemical Engineers for 1957. It is awarded annually for the best set of answers in the Associate Membership Examination of the Institution. The medal commemorates Mr. Macnab's close association with the Institution from the time of its foundation and his term of office as president in 1934. Mr. Wingrove is at present with the Dryer and Gas Plant Division of Birlec Ltd. as a project engineer and is engaged in the design of gas generators.

Meetings of the Month

Society of Chemical Industry

March 3. At 14 Belgrave Square, London, S.W.1. "Aspects of Polymer Fractionation", by Dr. J. H. Green. **6.30 p.m.**

March 4. At 14 Belgrave Square, London, S.W.1. Three papers on Corrosion. **6.30 p.m.**

March 18. At 14 Belgrave Square, London, S.W.1. "Economic Aspects of Corrosion", by A. Keynes. **6.30 p.m.**

March 19-20. At Beveridge Hall, University of London, W.C.1. Symposium on Costing in the Chemical Industry.

March 19. At Nottingham and District Technical College, Burton Street, Nottingham. "The Extraction of Thorium", by W. D. Jamrack, R. H. Wells and Dr. J. H. Buddery. **7.30 p.m.**

The Institution of Chemical Engineers

March 4. At Birmingham College of Technology, Gosta Green, Birmingham. "Reynolds' Analogy and Mass Transfer", by Prof. F. H. Garner, V. G. Jenson and R. B. Keey. **6.30 p.m.**

March 10. At Manchester College of Science and Technology, Jackson Street, Manchester. Symposium on Fluidisation. Whole-day meeting.

March 17. At Church House, Westminster, London, S.W.1. Spring Meeting. **9.30 a.m.**

The Society of Instrument Technology

February 24. At Manson House, Portland Place, London, W.1. Symposium on Automatic Weight Control in Industry. **5.30 p.m.**

February 26. *Grangemouth Section:* At Leapark Hotel, Grangemouth. "Design Characteristics of Control Valves", by A. M. Reid. **7 p.m.**

March 5. At Manson House, Portland Place, London, W.1. Symposium on the Use of Data Recorded on Industrial Plant. **5.30 p.m.**

March 10. *Manchester Section:* At "Manchester" Room, Central Library, St. Peter's Square, Manchester, 1. "Electro-magnetic Flow Meters", by L. M. Bennet. **6.30 p.m.**

March 19. *Tees-side Section:* At Cleveland Scientific and Technical Institute, Corporation Road, Middlesbrough. "Flow Measurement: Some Problems and Devices of Special Interest", by W. J. Clark. **7.30 p.m.**

Coming Events

March 17-19. At Royal Horticultural Society's New Hall, Greycoat Street, London, S.W.1. Oil and Colour Chemists' Association Eleventh Technical Exhibition.

March 17-21. At Earl's Court, London, S.W.5. Eighth Electrical Engineers' Exhibition.